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RADIO RECEIVERS WITH PUSH-BUTTON TUNING

by A. HOROWITZ and J. A. VAN LAMMEREN.

621.396.62

After a general survey of the various systems of push-button tuning (*i.e.* the reproduction of a number of previously fixed tunings by means of push buttons) a study is made of the system developed by Philips. In this system the rotating condenser is driven by a motor. The motor is started by pushing a button, and at the same time a stop is brought into position on a tuning cylinder corresponding with the button pushed. This stop determines the final position of the rotating condenser. Upon repeated pressing of the button the corresponding tuning is reproduced with a maximum deviation of 0.5 kilocycle per sec.

One of the most striking features in the development of radio receivers has been the attempt to simplify operation. This attempt on the one hand expresses the fact that the radio set, from a somewhat mysterious instrument which impressed the layman because of the technical achievement which it represented, has become an article of daily use. On the other hand the simplification of operation, and particularly of tuning, has become an urgent requirement, because inherent distortion of reproduction is now so much less that incorrect tuning by the listener is more noticable than it used to be. In other words, it is now more difficult for the listener to tune his set in such a way that the optimum effect is obtained. The resonance curve of present sets is smooth, and no wider than strictly necessary, which makes the adjustment to a definite wave length fairly critical. At the same time in sets with automatic volume control the listener can no longer be led by the intensity of the signal received [1]), but must judge the fidelity of reproduction which is greatest at the correct tuning point (lowest noise level). It is obvious that this offers certain difficulties and that such a receiver, especially when tuned by unskilled hands, would often be used at an incorrect tuning point. In order to avoid this, various measures have been applied from time to time. We may mention here visual indication, artificial reduction of sound intensity, resonance and tuning by touch.

An important advance is the completely automatic tuning realized in receivers operated by push buttons. The task of the listener in tuning is here reduced to the proverbial simplicity of "pressing the button". In general however the listeners would find it less enjoyable if they were compelled to listen only to a number of stations chosen by the manufacturer. This requirement of freedom of choice can be satisfied by retaining in the set, in addition to the push-button tuning, the ordinary dial tuning, and providing further that the push-buttons themselves can be set on different stations.

The advantage of the push-button tuning may then be summed up in the following way. The user is able to reproduce a number of tunings, which he himself has previously determined, by simply pressing the proper button. The accuracy of reproduction must of course satisfy high requirements if the advantage of the whole system is not to be illusory.

Various systems of push-button tuning

The various sytems of push-button tuning may be divided into two groups: those with electrical and those with mechanical pre-adjustment. The systems with motors form a special division of the second group.

In the systems with electrical pre-adjustment, the button which is pressed by the listener only serves as a switch. Each button switches in several semi-variable capacities or inductances which tune the set on a definite wave length. This method has the advantage that the push button need only be pressed lightly and need not be pushed in deeply. On the other hand there are various disadvantages. The setting of the push buttons is carried out by tuning the semi-variable components by means of screws. This is rather elaborate, and with the better kinds of receivers with more than two tuning circuits, in which therefore more than two parts must be adjusted for every station, the manipulation is impracticable for the ordinary user. Another difficulty of these sets is the alteration of the previously fixed tuning elements due to external influences such as shocks, variations in temperature, moisture, etc. In order to prevent the push buttons becoming completely detuned at times due to these causes, permanent capacities or inductances which are practically insensible to the influences in question are often used in circuit with the semi-variable elements. The latter then need form only a small part of the whole capacity or inductance, as the case may be. Small semi-variable elements may be made much more constant than large ones, and moreover their variations are relatively less important. This method limits the wave length zone over which the pre-tuning of one push button may be varied. If the wave length zones of the available push buttons are distributed over the whole wave length range of the broadcast, the user must then choose stations for the push buttons which are also distributed over this whole wave length range [2]).

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[1]) This is explained in Philips techn. Rev. **1**, 264, 1936.

The systems with mechanical pre-tuning have the inherent advantage of requiring no change in the electrical part of the receiving set. The push buttons act through a mechanical transmission system directly on the tuning condenser. Each push button moves the condenser to a definite, previously determined position. If one considers the wide angle which the plates of a rotating condenser can describe, it is obvious that a relatively large force must be applied or a great distance must be covered. Against this disadvantage, in addition to the advantage already mentioned, there is the fact that the accuracy of reproduction of the adjustment is determined wholly by the mechanical construction, and is therefore less sensitive to external influence [3]). The problem of the previous adjustment of the push buttons on the desired stations can be solved by means of relatively simple constructions. In connection with the reproducibility the following requirements must be fulfilled. When the button is not pressed in sufficiently far (because of carelessness of the user) it must nevertheless reach its final position or spring back again to its initial position. Furthermore the wear down to which this arrangement, like every other mechanical arrangement, is exposed may affect only the adjustment (which can easily be regulated again) and may not affect the accuracy of adjustment.

The motor-driven systems have the same advantages as the other systems with mechanical pre-adjustment, and in addition the advantage of the systems with electrical pre-adjustment, namely that the main function of the push button is that of a switch for starting the motor, and that a light pressure is therefore sufficient. The fact that the tuning manipulation itself is left to a motor makes it possible to increase the distance covered in that manipulation and this improves the accuracy of the adjustment, as we shall see later.

In the earliest sets with push-button tuning, where the accuracy of adjustment was still unsatisfactory, use was usually made (and sometimes still is) of automatic frequency correction. When incorrect tuning leads to the fact that the carrier wave, passed on the intermediate frequency part, does not have the same frequency as the permanently tuned intermediate frequency circuits, this frequency correcting circuit causes the oscillator frequency to be changed automatically so that the intermediate-frequency signal finally does assume the correct frequency. At the same time, however, the high-frequency circuits are far from correctly tuned, so that the chance of distortion and cross modulation becomes greater. Automatic frequency correction moreover necessitates the use of extra valves. In the push-button tuning system to be described sufficient accuracy is attained to make the application of automatic frequency correction unnecessary.

A motor-driven push-button tuning system

The system developed by Philips which we are about to describe makes use of a motor. The principle is the following: a push-button starts the motor and at the same time brings into position a stop which determines a definite final position of the rotating condenser. The motor turns the shaft of the rotating condenser and is switched off automatically when the stop is reached, *i.e.* when the rotating condenser has reached the proper position.

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[2]) This presents no difficulties in the United States because the distribution of wave lengths is such that stations which are neighbours geographically are suitably far away from each other in the ether, at least 50 kilocycles/sec. The stations which will naturally be chosen by a listener are therefore automatically fairly uniformly distributed over the whole wave length range. The situation in Europe in this respect is quite different.

[3]) Of course there always remains the slight spontaneous detuning also experienced in ordinary receivers without push-button tuning, which is due to the heating up of the apparatus in use. This can, however, be eliminated by carrying out the pre-tuning of the push-buttons only after the set has become warm.

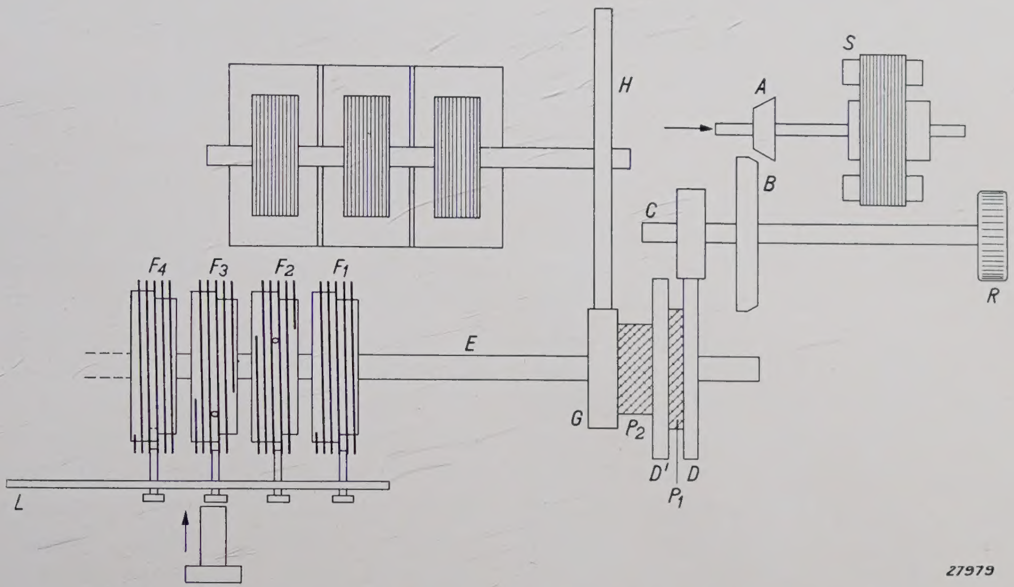


Fig. 1. Diagram of the mechanism of motor-driven push-button tuning. S = motor, A-B = friction drive, C-D and G-H = toothwheel transmissions, F_1, F_2 ... = tuning cylinders P_1 and P_2 = friction couplings; R = knob for hand tuning, L = contact bridge.

Fig. 1 shows the whole tuning mechanism diagrammatically. The motor S *via* two friction wheels A and B and a toothwheel transmission C, D turns a shaft E, on which are fixed a number of tuning cylinders F_1, F_2, ... The motion of the shaft E is transmitted by the toothwheels G, H, to the rotating condenser in a transmission ratio of 1 : 5. When the condenser moves from minimum to maximum capacity, *i.e.* a half turn, the tuning cylinders make $2^1/_2$ turns. *Fig. 2* is a photograph of a single tuning cylinder. A helical groove of five turns is cut on the surface of the cylinder. Along this groove moves a peg which is fastened to one end of a fairly long strip, T, the other end of which is fastened in such a way that it can rotate about a horizontal and a vertical axis (see photograph *fig. 3*). In this way the peg easily moves up and down as well as from side to side to follow the spiral groove. Exactly in the middle of the cylinder, *i.e.* $2^1/_2$ turns from either end, there is a hole bored in the cylinder into which the peg fits. When the peg is pressed against the bottom of the groove by means of the push button, and when the cylinder turns, the peg will slip into the hole at a given moment and prevent further motion of the tuning cylinder and also of the rotating condenser. The strip to which the peg is fastened due to its rather elastic flexibility takes up the kinetic energy of the whole mechanism (*i.e.* of the rotating condenser, the tuning cylinders and the toothwheels).

Actually the peg is not pressed down by the push button itself, but by a spring which is freed for action by the pressing of the button. In this way it was made possible for the push button to be pushed in immediately to its full depth, and the user need not keep his finger on the button until the peg has slipped into its hole. A simple locking arrangement (see Q in *Fig. 4*) holds the button in the final position and makes it spring back as soon as another button is pressed.

When the rotating condenser is in any arbitrary position, it will have to rotate to the right to reach some stations and to the left for other stations. The groove in the tuning cylinder is cut to two different depths: the bottom of the left-hand $2^1/_2$

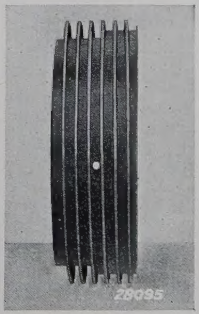


Fig. 2. Photographs of a tuning cylinder. The left-hand windings of the groove are somewhat deeper than the right-hand ones.

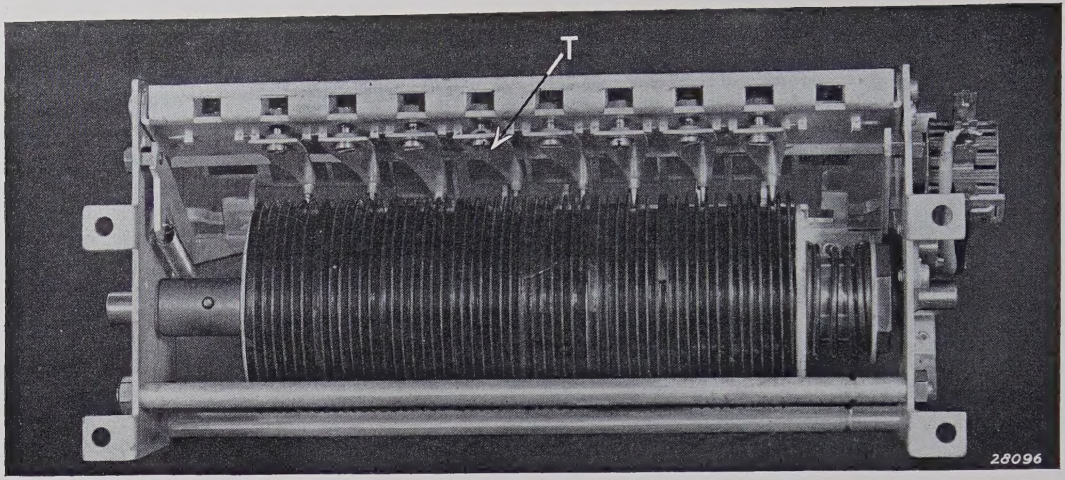


Fig. 3. Photograph of the keyboard, taken from the rear. The long strips carrying the pegs may be seen. To the right are the contacts which serve for starting and reversing the motor. The third from the left is pushed down.

windings is deeper than that of the right-hand windings. When the peg is down it takes with it the bridge *L* which extends over all the tuning cylinders and moves several contacts at the side of the keyboard (see photograph, fig. 3, right-hand side). If the peg is to the left of the hole, it, and with it the contact bridge, will be somewhat lower when the peg is pushed down than when the peg is to the right of the hole. In the two different positions of the contact bridge two different contacts are made and the motor turns in one direction or the other according to which contact is closed. In this way provision is made that the rotating condenser is always turned automatically in the direction in which the peg must travel to reach the hole, and the condenser is thus rotated over the smallest possible angle to the position corresponding with the station chosen.

We shall now examine the commutation arrangement of the motor. In *fig. 5* the group of contacts *I* to *IV* is drawn separately. The contact piece *k* which is fastened to the above-mentioned bridge *L* is directly connected with the contact spring *II*. The bridge may now assume four different po-

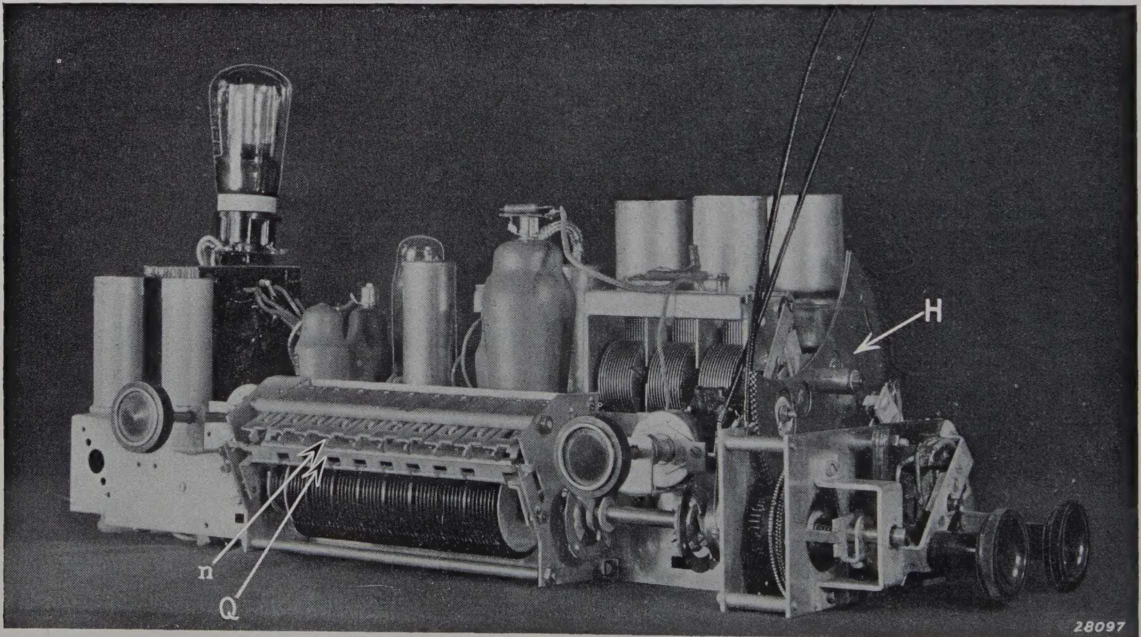
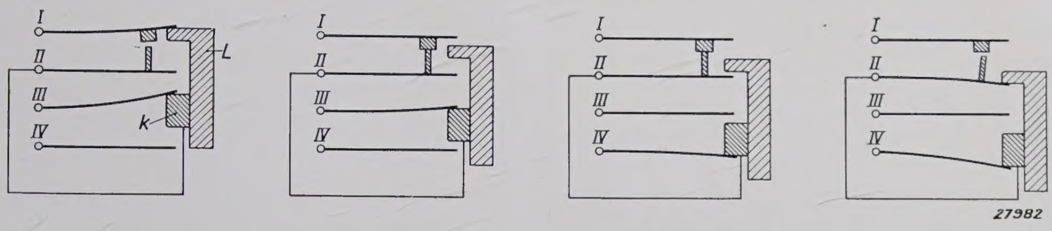


Fig. 4. Photograph of the push-button tuning arrangements mounted in the receiver. In the middle is the keyboard, to the right the motor and transmission. The locking arrangement *Q* holds down the key pressed: the end of the key *n* falls into the corresponding opening of the beam *Q*. When another key is pressed the beam *Q* is first pushed away against the action of a spring (visible in fig. 3 to the left), and the key previously held is thereby released.

sitions. If none of the buttons is pressed down the bridge is drawn up by a weak spring in position *a* (fig. 5*a*), in which the springs *I* and *II* make no contact with each other and the motor is therefore not in action (see fig. 6*b*). If a button is now pressed down, as we have already explained, a peg and with it the contact bridge are pressed down by a stronger spring. If the peg of the tuning cylinder in question rests on the shallower part of the groove the contact bridge is in position *b* (fig. 5*b*). The contact *I* - *II* closes and the motor starts. In this position there is contact between the terminals *II* and *III*, which corresponds to a certain direction of rotation of the motor. If the peg rests on the deeper part of the groove the bridge assumes position *c* (fig. 5*c*) where *I* and *II* still make contact, but where *II* is connected with *IV*, and the motor turns in the other direction. As soon as the peg slips into the hole in the tuning cylinder the contact bridge falls somewhat lower still, into position *d* (fig. 5*d*). The contact *I* - *II* is here open again, the motor is therefore switched off and the receiver is tuned in to the desired station.



a *b* *c* *d*

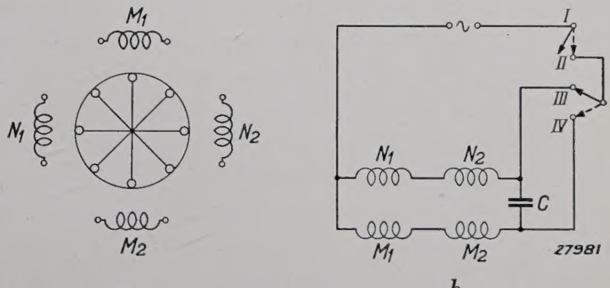
Fig. 5*a* - *d*. Position of the contacts *I* - *IV* in the four different positions of the contact bridge *L*.

Fig. 6a gives a diagram of the motor. A drum armature is situated between four poles. The coils M_1 and M_2, as well as N_1 and N_2 are connected in series. Fig. 6*b* gives the diagram of the circuit. If the contacts *I* - *II* - *III* are connected (position *b* of the contact bridge *L*, fig. 5*b*), the presence of the condenser *C* causes the phase of the current in the pair of coils N_1 - N_2 to lag behind that of the current in the coils M_1 - M_2. Due to the phase shift of the two perpendicular fields, the resultant field is rotating and a couple is produced on the drum armature. If, however, the contacts *I* - *II* - *IV* are connected (position *c* of the contact bridge *L*, fig. 5*c*), the phase of the current in the pair of coils N_1 - N_2 is ahead of that in M_1 - M_2, the field (and therefore also the drum armature) now turns in the opposite direction.

Upon switching on the motor the drum armature, which, due to the action of a spring, is held somewhat outside of the axis of the coils, is drawn into the magnetic field and thus displaced axially against the spring. The friction drive *A*, *B* (fig. 1) thereby begins to work. At the moment when the motor is switched off, the axle of the drum armature springs back and the motor can come to rest freely. The relatively high kinetic energy of the motor is in this way unable to damage the precise mechanism of the tuning.

The axis of the toothwheel *C* in fig. 1 can be turned by hand with the knob *R*. In this way ordinary continuous tuning may be carried out. Considering the high transmission ratio of the toothwheels *C*, *D* and *G*, *H*, the user would have to turn for some time the rotating condenser from one final position to another. In order to facilitate this process two additional keys are added to the keyboard to the right and left of the station keys. These additional keys serve to set the motor in motion in either direction, and may be used by the listener to bring the dial pointer into the neighbourhood of the desired station. The accurate tuning may be then carried out by hand.

If it is desired to change over from push-button to hand tuning, the last button pushed in must be made to spring back to its initial position. However, the mechanism is made fool-proof in this



a *b*

Fig. 6*a*. Diagram of the motor. A drum armature rotates in the field of four coils M_1, M_2, N_1 and N_2.

Fig. 6*b*. Circuit of the motor. *C* is a condenser which provides for the necessary phase shift in the currents in the pairs of coils M_1-M_2 and N_1-N_2.

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[4] Incidentally it may be noted that with this displacement of the shaft of the armature a contact is also closed which connects a condenser in parallel with the loud speaker. During the process of tuning, therefore, almost no sound is heard.

respect: between the toothwheels D and D' (fig. 1) the shaft E is broken and a rather weak friction coupling P_1 joins the parts. If the user turns the tuning knob R when the whole mechanism is locked by the peg in the tuning cylinder, the coupling P_1 slips and the toothwheel D_1 does not move.

The tuning knob R also serves for pre-adjustment of the push buttons on the desired stations. For this purpose the knob must be pushed in slightly. The toothwheel C then catches in D_1 directly and the friction coupling P_1 is out of action. The tuning cylinders F_1, F_2 ... are not fastened immovably to the shaft E, but are movable by a frictional force stronger than that in the coupling P_1. If a tuning cylinder, F_3 for example, is held by the corresponding peg, and if the slightly depressed tuning knob is then turned, all the other tuning cylinders turn with the shaft E. If one tunes in to a station in this way, the push button of cylinder F_3 in then set on that station. The pre-adjustment of the push buttons thus takes place in the same way and even with the same knob as ordinary hand tuning. The dial which is turned by the shaft E also turns at the same time.

When the rotating condenser is in one of its two end positions and the user tries to turn the tuning knob still further, the friction coupling P_2 between the toothwheels D' and G begins to slip, so that no harm results. For satisfactory functioning of the mechanism the friction in the coupling P_2 must of course be greater than that which causes the cylinders F to turn with the shaft E.

Construction of the motor

The motor is so constructed that it works not only on ordinary alternating current of 50 cycles but also on alternating current supplied by a vibrator [5]). The latter current has a higher frequency, namely 100 - 120 c/s. When one keeps in mind that the inductive resistance of the windings (see fig. 6*b*) and the capacitive resistance of the condenser takes on different values at the higher frequency, it is obvious that the motor has to fulfil different requirements in the latter case. The result is that the starting couple of the drum armature becomes smaller and the number of revolutions with no load becomes higher. By a suitable construction of the drum armature the couple has been made great enough even at the higher frequency. A regulator has been introduced on the axle of the armature which provides that even at the higher alternating current frequency the number of revolutions of the motor is not too high. At the vibrator frequency the axial force on the drum armature becomes smaller and due to this the friction drive A B (fig. 1) may begin to slip. The regulator on the axle of the armature is so constructed that the segments, forced away from each other by centrifugal force, have a tilted motion and in this way exert not only a braking effect but also a force in the axial direction, so that the total pressure is sufficient for the friction drive A, B.

Accuracy of tuning

In spite of the fairly complicated working of the mechanism an excellent degree of reproducibility has been attained. This is due in the first place to the fairly high transmission ratio (1 : 5) between the axle of the tuning cylinders and that of the rotating condenser. In any case the reproducibility will depend upon the amount of play of the peg in the hole in the tuning cylinder. This play will be of less importance the longer the path covered by the peg on its way to the hole. When the condenser is turned from minimum to maximum capacity, *i.e.* half a turn, the tuning cylinder makes $2^1/_2$ turns; with a cylinder diameter of 44 mm therefore the relative path of peg and hole is about 350 mm. If we assume that the frequency of the apparatus varies approximately in proportion to the angle of rotation of the condenser, and therefore also in proportion to the distance between peg and hole, and if the frequency on medium waves increases for instance from 500 to 1500 kc/s upon a half turn of the condenser, then a play of 0.1 mm means a variation in frequency of about $0.1/350\ (1500 - 500) \approx {}^1/_3$ kc/s. The maximum deviation in reproduction of a given push-button tuning is actually found to amount to not more than 0.5 kc/s. Of course it was necessary to suppress any backlash in the toothwheel transmission G, H (fig. 1), between tuning cylinders and rotating condenser. This was done by means of the following method of construction. The toothwheel H (see fig. 4) consists of two exactly similar toothwheels which are placed next to each other on the shaft. One of them is fastened to the shaft, the other is carried along by a spring acting in a tangential direction and fastened to both toothwheels. The driving toothwheel G engages with both toothwheels of H at the same time; by means of the spring one tooth of G is always clamped firmly between a tooth of one and a tooth of the other two toothwheels H, and there can be no play.

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[5]) *Cf.* Philips techn. Rev. **2**, 346, 1937, for details of a vibrator for the supply of A.C. sets from D.C. mains.

X-RAY TUBE FOR THE ANALYSIS OF CRYSTAL STRUCTURE

by J. E. DE GRAAF and W. J. OOSTERKAMP.

621.386.1: 548.73

The following special requirements must be made of an X-ray tube which is intended for the analysis of crystal structure: the exposure time required must be short, the radiation must be spectrally pure and the operation of the tube must be easy. A tube with water-cooled anode which satisfies these requirements is described. Special attention is paid to the shape of focus necessary to obtain the greatest possible brightness. The problem of heat conduction connected with the cooling of the anode is dealt with.

There exist in the main two large fields for the application of X-rays: medicine and the testing of materials. In medicine X-rays are used for diagnostic and therapeutic purposes, in the testing of materials for detecting macroscopic defects [1]) and for studying crystal structure by means of diffraction diagrams [2]).

The requirements made of the X-ray tube are different for each of these two applications. To name a single example: in certain therapeutic applications of X-rays, where use is made of their destructive effect upon tissues, it is of foremost importance that the rays possess high penetration and energy. The shape of the focus (*i.e.* the spot where the X-rays originate) is of less importance; it may be fairly large. In the other applications mentioned where it is a question of obtaining an image of internal details or a diffraction diagram, it is very important that the focus be small for the sake of sharpness of the image or diffraction diagram. On the other hand there are also conditions which must be kept in mind in the construction of all kinds of X-ray tubes, among others are the protection of the operator against X-rays other than those of the beam directed on the object, and the safeguarding against the high voltages necessary for the working of the tubes.

In this article we shall deal with a tube which has been developed especially for use in the analysis of crystal structure, not only in scientific and technical laboratories, but also in the workshop. For a detailed description of the procedure in the different branches of structure analysis (with a single crystal according to **Laue**, with a powder according to **Debye** and **Scherrer**, investigation of stresses, etc.) we refer the reader to the series of articles by **Burgers** [2]). The various possible arrangements all have the common feature that the beam of X-rays coming from the tube is first reduced by means of a diaphragm to a narrow ray; this ray then falls upon the substance to be examined. It is then deflected or reflected in different directions, which are determined by the crystal structure, and a blackening occurs at corresponding points on a photographic film situated at some distance from the substance (*fig. 1*).

In the construction of the X-ray tube which we are about to describe the following points have been especially considered:

1) The required exposure times must be as short as possible. This is important not only for routine work, but also for scientific research, where reasonable exposure times are desirable even in the case of poorly reflecting substances or when a small opening of the diaphragm is used.
2) The radiation must possess a pure spectrum. When this is not the case the undesired spectrum lines themselves give rise to interference images, and in this way make the diagrams much more complicated and their interpretation unnecessarily difficult.
3) The tube must be easily handled and adjusted, especially for industrial purposes.

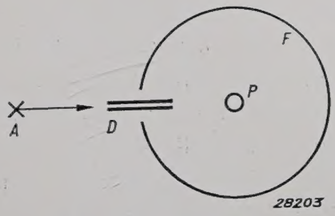

Fig. 1. Diagram of an arrangement for crystal structure analysis. A = focus from which the X-rays are emitted, D = diaphragm, P = substance, F = film.

Construction of the tube

Fig. 2 is a diagram of the construction of the tube. The hot cathode K emits electrons which are accelerated by a potential difference of 20 to 40 kilovolts in the direction of the anode A. At the anode a small part of the kinetic energy of the electrons is transformed into X-radiation, the greater part, however, into heat. The anode is soldered into a chrome-iron can D, to which the glass part G which bears the cathode is fused. This construction makes it possible to cool the anode with water, so that an efficient dissipation of heat is attained. The cooling water flows in and out at *W*. At *L* there are glass windows in the anode can through which the X-rays are emitted to the outside. A metal cylinder *B* kept at cathode potential surrounds cathode and anode. The wall of the cylinder has only several small openings for the passage of the X-rays. In this way provision has been made against secondary electrons from the anode being able to bombard the window *L*. A lead jacket *P* surrounds the anode can and captures all X-rays except the beam passing through the windows.

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[1]) See the five articles by J. E. de Graaf on this subject in the 2nd and 3rd volumes of this periodical.

[2]) See the twelve articles by W. G. Burgers on this subject in the 1st and 2nd volumes of this periodical.

The anode is earthed, so that it is not necessary to have an insulated pump with a closed water circuit for cooling, but water from the mains may be used. Since the cathode is at high potential (which is supplied *via* the high tension cable *H*) the heating current transformer must be insulated. This transformer is built in with the high tension transformer. The whole tube is placed in a metal container *M* which, like the metal covering of the high tension cable, is earthed, so that it is impossible for the user to come into contact with current bearing components. The cathode is mounted in the opening of a plate *C* which is kept at cathode potential. This plate with its opening acts as an electron lens, *i.e.* it causes such a deflection in the paths of the electrons that they are focussed sharply on the anode. By giving the cathode a suitable form, a focus of given shape and dimensions can be obtained.

Short exposure times

We shall now discuss the way in which the requirements mentioned at the beginning of this article are fulfilled. There are various important factors in obtaining a short exposure time, for example, the filter of the tube itself. In order to pass from the vacuum in the tube into the outer atmosphere, the X-rays must inevitably pass through a wall by which they are weakened. The weakening is kept as small as possible in the tube described by making the windows *L* (*fig. 2*) of Lindemann glass, which contains only elements with a low atomic number and therefore absorbs only little of the radiation. Moreover, the windows are very thin, namely 0.12 mm in thickness. This type of window was made possible by the above-mentioned protection of the windows from bombardment by secondary electrons from the anode. The active radiation obtained with a copper anode is weakened only 25 per cent by the windows.

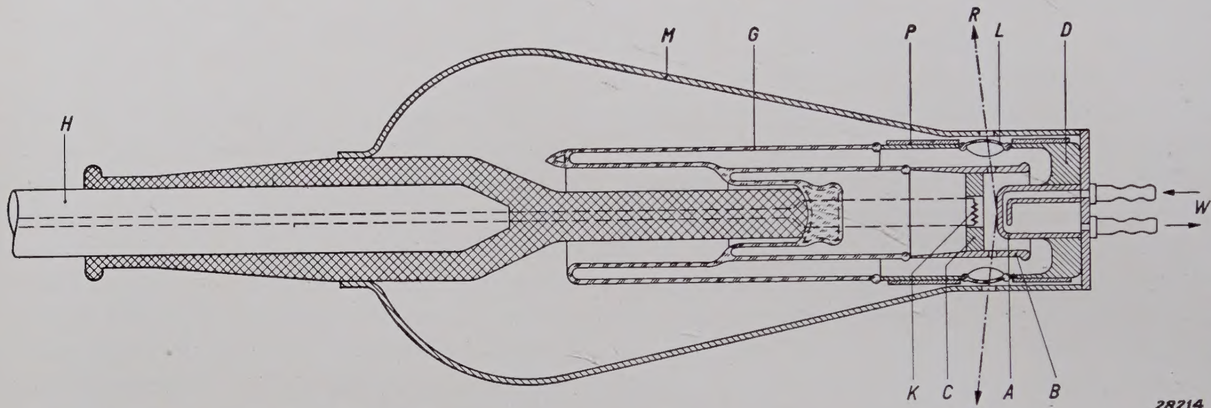


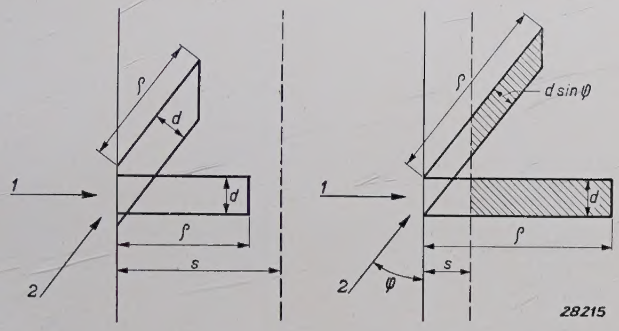
Fig. 2. Construction of the X-ray tube for structure analysis. The anode *A* is part of the chrome-iron can *D*, to which is fused the glass part *G*, which bears the shielding cylinder *B* with the plate *C* and the cathode *K*. The X-rays pass through the windows *L* in the direction of the arrows *R*. At *W* the cooling water flows in and out. The tube is placed in a metal container *M* which, like the anode and the metal covering of the high tension cable *H*, is earthed. A lead jacket *P* surrounds the anode can.

Furthermore it is clear that the exposure times may be chosen shorter the closer the camera can be placed to the focus: the intensity of the radiation is inversely proportional to the square of the distance. The minimum distance is determined by the diameter of the tube. This latter is closely connected with the maximum voltage to be used, since the distance between the shielding cylinder *B* and the anode necessary to avoid breakdown increases proportionally with the voltage to be used. In order to be able to use the tube for Laue diagrams also, where relatively high voltages are necessary, the maximum permissible voltage was fixed at 60 kilovolts (for alternating as well as for direct voltage). Nevertheless, because of the compact construction of the components in the anode can, the diameter is only 60 mm, so that the camera may be brought up to a distance of about 35 mm from the focus.

The most important factors for obtaining short exposure times are, however, the shape and the brightness of the focus. The first method that would occur to one, to increase the intensity of the X-ray beam, would be to increase the dimensions of the focus and choose correspondingly greater diaphragm openings. This method, however, as was mentioned in the introduction, is limited by the lack of sharpness which would result from too large a source of radiation. In general, for making crystal structure diagrams a diaphragm opening of 1 mm diameter [3]) at the most is used, and it is therefore useless to make the source of radiation much larger than 1 × 1 mm. When the surface to be irradiated is determined, the X-ray energy can only be increased by increasing the brightness of the focus.

Shape and brightness of the focus

The fact that X-radiation does not follow Lambert's law may be utilized in determining the shape of the focus. According to that law the brightness of a radiating surface is the same from all directions, and it is valid in the case of so-called body radiation. If one looks normally at the surface, for instance of a volume of incandescent gas of the thickness s (arrow *1*, *fig. 3a*), the outermost layer as well as the deeper layers contribute to the light observed. The light of the more deeply lying parts will, however, be weakened by absorption, and it will be more weakened the more deeply its source lies in the gas. After a definite depth ϱ practically no more contribution will be made to the light leaving the surface. If one looks obliquely at the surface of the incandescent mass (arrow *2*), a column of the length φ will again contribute to the observation of light, and with the same diameter of column as in the first case, *i.e.* from the same apparent surface, the same light intensity is obtained. This means that the brightness (light intensity/apparent surface) is the same in both directions. From fig. 3*a*, however, it may be seen immediately that the above deductions are only valid for body radiation, *i.e.* when the depth s of the layer in which the light emitting processes take place is greater than the depth ϱ of the layer which contributes to the light leaving the surface. Fig. 3*b* shows the opposite case, where $s < \varrho$, *i.e.* a surface radiation. The cross hatched areas of the column (whose length is determined only by the absorption in the substance of the radiation emitted) now contribute nothing, since no light-emitting processes take place in those areas. When the column has an oblique position that part of it which can cause radiation to be emitted from the surface becomes longer. If one now considers the emission from the same real surface, the same light intensity is obtained in both directions, because the volume of the column which contributes has remained the same (oblique cylinders with equal bases and equal altitudes). Considering, however, that in the oblique direction the apparent radiating surface is smaller, the brightness in the oblique direction will be greater than in the normal direction of observation. *Fig. 4* shows the dependence of brightness on the angle of observation for both cases, body radiation (*I*) and surface radiation (*II*).



a *b*

Fig. 3*a*) Body radiation. The depth s of the emitting layer is greater than the depth λ of the layer which contributes to the light emitted. Upon normal (*1*) and oblique (*2*) direction of observation the same light intensity is obtained from the same apparent surface (d). The brightness is therefore the same in all directions (Lambert's law).

b) Surface radiation. In this case $s < \lambda$. With oblique direction of observation (*2*) the same light intensity is obtained from the apparent surface $d \sin \varphi$, as is obtained with normal observation (*1*) of the surface d. The brightness in the oblique direction is greater ($1/\sin \varphi$ times) than that in the normal direction.

In the case of X-rays we are actually concerned with a surface radiation. The absorption of X-rays in the material of the anode is much less than that of the bombarding electrons. The electrons excite X-radiation in only a thin layer (thickness $s = 0.01$ mm, for instance), while the radiation would be

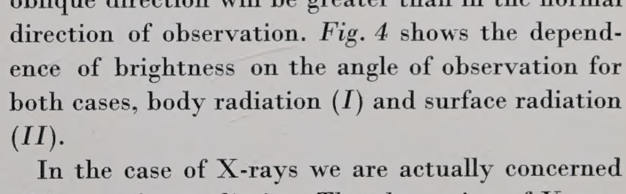


Fig. 4. Polar diagram of the brightness with volume radiation (*I*) and surface radiation (*II*). At small angles the straight line *II* bends toward a circle (Lambert's law, as in *I*). At still smaller angles the irregularities in the surface of the anode become noticeable and the brightness diminishes toward zero (indicated by dotted line).

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[3]) For special cases smaller diaphragm openings are also used, 0.5 or 0.25 mm.

able to leave the surface from much greater depths (ϱ) (fig. 3*b*). If the focus is made oblong in shape, for instance a rectangle with the width b and the length $l = b/\sin\varphi$ (line focus *fig.* 5), a radiating square of side b is observed in the direction φ, and its brightness is a factor $1/\sin\varphi$ greater than upon normal observation. This principle was first applied in X-ray tubes by Goetze.

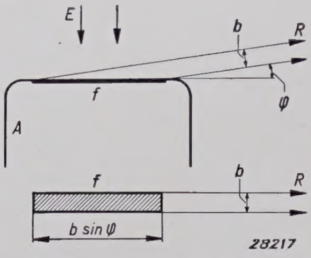

Fig. 5. Shape of the focus on the anode A. The electrons fall perpendicularly upon the anode (E), the X-rays are observed at the angle φ (R). The width of the focus is b, the length $b/\sin\varphi$, so that the focus is observed as a square in the direction φ.

From fig. 3*b* it may be seen that with a very small angle between the direction of observation and the surface the above considerations no longer hold, because the whole column with the length ϱ then falls in the emitting layer of thickness s. In the latter case Lambert's law again holds, and the straight line II (constant light intensity) in fig. 4 bends around toward a circle [4]). After a definite angle therefore, further reduction in that angle produces no further increase in brightness. Moreover, at small angles to the surface slight irregularities in the anode (due to the roughening of the surface, see below) have a disturbing effect. For these reasons in the tube described the angle between the direction of observation and the surface of the anode is chosen at 6°. In order to be able to carry out the focussing easily even at the largest diaphragm openings used (1 mm), the apparent dimensions of 1.2 × 1.2 mm were chosen for the focus; the actual dimensions are therefore 1.2 × 12 mm ($\sin 6° \approx 0.1$). The line focus has two identical directions of observation. For certain applications a direction perpendicular to these may also be used, so that four windows in all have been introduced [5]).

Specific loading of the focus

With given shape and dimensions of the focus the brightness may still be increased by increasing the specific load (the energy given off by the electrons per square centimeter and per second). The brightness is proportional to the specific load at constant voltage. However, the heat developed also increases proportionally, so that the temperature in the neighbourhood of the focus becomes higher. The permissible temperature of the anode is limited by the occurrence of evaporation of the focus material which causes the focus to become more or less rough. The requirement is made that the erosion of the focus after 1000 or 2000 hours use must not exceed a certain limit which is connected with the above-mentioned decrease in brightness at small angles. This requirement therefore fixes a maximum permissible rate of evaporation, *i.e.* a maximum permissible temperature for every focus material.

As much heat as possible must be developed on the focus (high specific load), but the maximum permissible temperature must not be exceeded. It is therefore a question of conducting the heat away as well as possible. The heat dissipation takes place chiefly by conduction in the anode material toward the rear wall (*fig. 6*) which is cooled with running water, and which has a practically even temperature over the whole surface cooled. This temperature must remain everywhere lower than 100 °C, since otherwise the cooling water would begin to boil with the result that an insulating layer of steam would be formed and finally boiler-scale. This limitation of the temperature of the cooled surface determines the heat flux to be handled per unit of the cooled surface at a given rate of flow of the cooling water. The specific load W_f of the focus which can be reached under the two conditions mentioned: maximum permissible focus

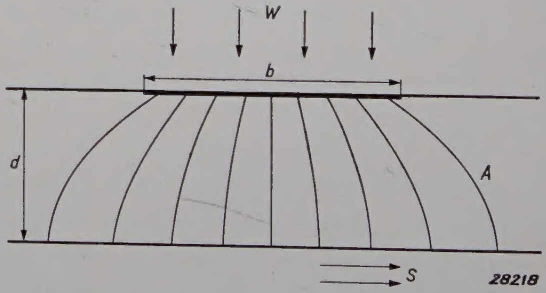

Fig. 6. The problem of heat conduction at the anode. At the focus f (whose longest side must be imagined perpendicular to the plane of the drawing) the heat flux W is developed. The heat is conducted through the body of the anode A to the rear wall where cooling takes place by means of running water s. As is indicated a divergence in the lines of heat flux occurs which is more pronounced the greater the thickness of the anode d.

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[4]) Actually the deflection only appears at much smaller angles than that drawn in fig. 4. With a given monochromatic X-radiation F. Wisshak (Ann. Physik **5**, 507, 1930) found that at $\varphi = 20°$ the brightness was 2.8 times, at 10°, 5.2 times, and at $\varphi = 6°$ 8.1 times as great as with normal observation ($\varphi = 90°$).

[5]) In principle it is possible to apply several such foci to the anode in different directions (by means of several cathodes) and thereby to make more than two normal photographs at the same time.

temperature and maximum permissible density of heat flux on the cooled surface, depends upon the thickness d of the anode. At a certain thickness of the anode the value which may be assumed by W_f reaches a maximum. This may be explained in the following way.

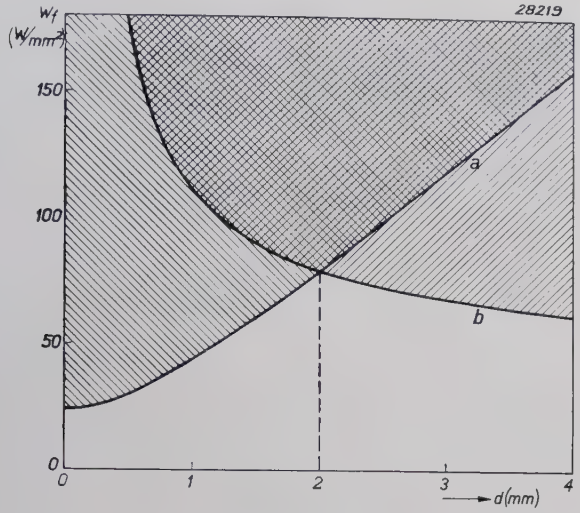

Fig. 7. Dependence of the specific focus loading W_f on the thickness of the anode d, with an infinitely long line focus 1.2 mm wide on a copper anode. In curve a the density W_s of the heat flux at the cooled surface is at its maximum permissible value (24 W/sq.mm). In curve b the focus temperature T_f is at its maximum permissible value (300 °C), while the temperature of the water-cooled surface is fixed at 100 °C (in the case of curve a this condition was automatically fulfilled). The "permitted" region is below both curves. The thickness d which corresponds to the point of intersection of the curves is the optimum thickness. The curves are calculated for a constant loading (direct current); the maximum value of W_f attainable, when $d = 2$ mm, is then 80 W/sq.mm. When alternating current of the same effective value is used the attainable value of W_f becomes smaller, namely 60 W/sq.mm.

In *fig.* 7 W_f is plotted against d. Curve a is calculated for the case where the density of heat flux W_s is always at its maximum permissible value, which is here assumed to be 24 W/sq.mm. The temperature of the focus is disregarded in curve a. With a very thin anode (small d) the lines of heat flux run practically parallel to each other toward the rear wall, *i.e.* the density of heat flux is uniform, and W_f may therefore be no greater than W_s (24 W/sq.mm). If the anode is thicker (larger d) a certain divergence of the heat flux appears in the heat conduction (see the lines of flux in fig. 6), so that the density of the heat flux is smaller at the rear wall than at the focus. The permissible value of W_f therefore becomes greater than W_s; in the first approximation it increases proportionally with d. The region above the curve is "forbidden", because every point in that region represents a combination of W_f and d, where W_s would be greater than 24 W/sq.mm. Curve b is calculated for the case where the focus temperature T_f is always at its maximum permissible value, which is here taken as 300 °C (copper anode). In this curve the density of heat flux at the cooled surface is disregarded but it is assumed that the rate of flow of the cooling water is always high enough, so that the cooled surface maintains a temperature of 100 °C. Along the curve therefore the temperature difference between focus and cooled surface is constant and equal to 200 °C. At very small values of d the temperature gradient, and therefore also the heat flux in the anode which is proportional to it, must be very great in order that the temperature difference between the two surfaces may reach the figure mentioned. In this case therefore W_f is very great. At greater values of d the temperature difference mentioned is attained with a smaller gradient and therefore smaller value of W_f. Here again the region above the curve is "forbidden", since at every point in that region the focus temperature would be higher than 300 °C.

If it is now desired to satisfy both conditions, that for T_f and that for W_s, then only that region is "permitted" which lies not only below curve a, but also below curve b. It is clear that with a given thickness of anode d, namely that which corresponds to the intersection of the two curves, the greatest specific loading of the focus W_f is attained.

This optimum thickness of wall depends upon the rate of flow of the cooling water, since this rate of flow determines the permissible density of heat flux at the rear wall of the anode. Moreover it is, of course, not the same for different anode materials with their different physical constants. Since, however, these materials are only applied in the form of a thin plate to a base of copper, the mutual differences between the corresponding optimum thicknesses of wall are not great. The thinner the plates applied, the better the heat dissipation and the higher the specific load. In the tube here described the rate of flow of the water is 5 m/sec, for which a pressure of 1 atmosphere and a consumption of water of 6 litres/min. is necessary. The optimum wall thickness is then about 2 mm, and the permissible specific load with a copper anode is 60 W/sq.mm, when the tube works on alternating voltage and the line focus is 1.2 mm in width. For the sake of comparison it may be added that with the aircooled "Metalix" tube for structural analysis [6]) the specific load is 25 W/sq.mm and with another watercooled tube [7]) 30 W/sq.mm (both tubes having copper anodes).

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[6]) A. Bouwers and W. Busse, Z. Krist. **77**, 507, 1931.

[7]) R. Glocker, Materialprüfung mit Röntgenstrahlen, 1936, p. 167.

For iron, cobalt and chromium in the tube described a specific load of about 35 W/sq.mm is permissible, for tungsten and molybdenum about 70 W/sq.mm, when these metals are soldered to the copper base of the anode in the form of plates 0.5 mm thick.

Homogeneity of the focus loading

Fig. 8 shows the distribution of temperature over the width of the line focus. In the calculation of this curve (as in the curves of fig. 7) the line focus is assumed to be infinite in length, which gives a satisfactory approximation. It may be seen from the curve that the temperature at the edges of the focus is about 20 per cent lower than in the middle. This phenomenon, which may be ascribed to the lateral dissipation of heat from the focus to the adjacent anode material, occurs with the homogeneous loading of the whole surface of the focus which has been assumed until now. When, however, the cathode has the form of a spiral the loading of the focus is not homogeneous. Equal numbers of electrons are emitted per sq.cm of the whole surface of the spiral. They are drawn immediately toward the anode by the strong field. It is reasonable to suppose that the paths of the electrons which are emitted from parts of the spiral whose tangents are intercepted by the focus will lie closest to each other. Therefore the current density is greatest at the outside of the electron beam, and consequently the focus is more heavily loaded at the edges than in the middle. Therefore with a cathode in the form of a spiral the temperature distribution over the width of the focus will not have the form shown in fig. 8, but will be more nearly constant over the whole width (it may increase slightly at the edges). Considering the fact that the temperature permissible for the focus material is nowhere exceeded, and that nevertheless a higher average specific loading is obtained, one might think that the lack of homogeneity of the focus loading would even be advantageous. In the case of certain kinds of X-ray tubes for medical diagnosis use is actually made of this feature. For crystal structure analysis, however, non-homogeneous focus loading is not allowable. When the edges are more heavily loaded they cause separate interference images due to their greater brightness, and these images are shifted somewhat with respect to each other, so that the impression is given of splitting or lack of sharpness of the interference lines or points. This phenomenon is illustrated in *fig. 9* by a Laue diagram [8]), in which the loading of the focus was exceedingly bad

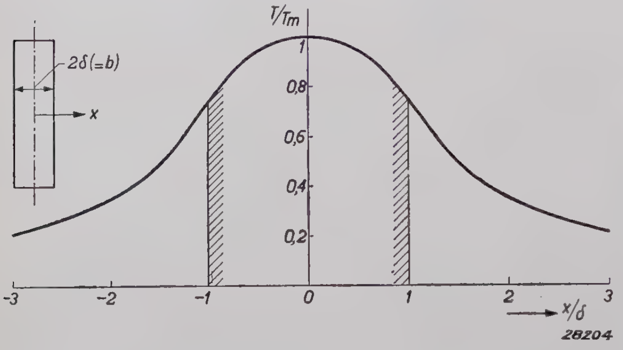

Fig. 8. Temperature distribution over the focus in the case of homogeneous loading. At the edges of the focus ($x = \delta$) the temperature is about 20 per cent lower than in the middle.

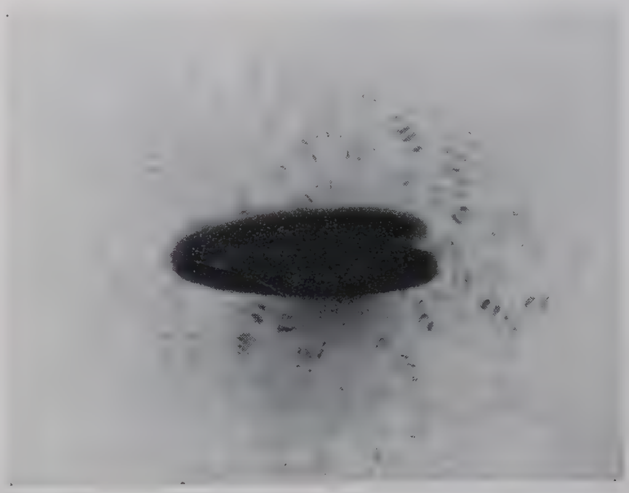

Fig. 9. A Laue diagram in which, due to very non-homogeneous loading of the focus, different mutually displaced interference images have been formed at the same time. This photograph should be compared with a good Laue photograph, such as given in this periodical **1**, 213, 1936.

An ordinary spiral cathode may therefore not be used, the cathode must have such a form that a homogeneous loading of the focus is obtained with a temperature distribution like that in fig. 8. This has been achieved, in the tube described, by means of a filament the emitting parts of which lie in a single plane parallel to the anode. In *fig. 10* are photographs of a focus with non-homogeneous loading and one with homogeneous loading, as well as their brightness distributions recorded with a microphotometer.

Purity of the spectrum

In the introduction the requirement was mentioned that the X-ray spectrum produced by the tube must be pure, and reasons were given for this requirement. The bombarding electrons excite in the anode metal an X-radiation with a continuous spectrum upon which is superposed a spectrum consisting of a few lines. This line spectrum is characteristic of each chemical element. In most of the applications of the tube, such, for example, as investigation by the Debye-Scherer method, a monochromatic X-radiation must be used. For every anode material a filter may be chosen of an element with a somewhat lower atomic number such that practically only one line of the characteristic spectrum is allowed to pass. If the surface of the anode is contaminated with another element, this element also emits its own characteristic radiation, which is, however, not entirely absorbed by the filter chosen, so that it is generally impossible in such a case to obtain a monochromatic radiation. For the sake of the purity of the spectrum, therefore, it is essential to avoid all contamination of the surface of the anode.

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[8]) This photograph was kindly supplied by R. Stephen of London.

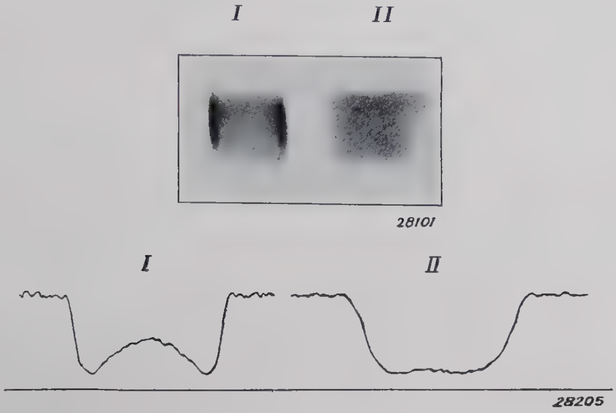

Fig. 10*a*) Photographs of a focus with non-homogeneous (*I*) and one with homogeneous (*II*) loading. The blackening is caused by the X-radiation emitted from the focus.

b) Photometer curves. The perpendicular deviation with respect to the horizontal zero line is proportional to the transmissibility at the successive points of a cross section of the photographs in *a*. Small ordinates thus correspond to heavy blackening and therefore to great X-ray intensity. With the non-homogeneously loaded focus (*I*) the brightness at the edges is considerably greater than in the middle.

The most commonly occurring contamination is tungsten evaporated from the cathode. Since the anode is situated close to the cathode to improve the electron focussing, the evaporating tungsten can easily condense on the anode. At the usual cathode temperature of 2400 °K the rate of evaporation of metallic tungsten is still very low. If, however, the tube contains water vapour the glowing tungsten is oxidized and the oxide evaporates much more rapidly than the pure metal. The oxide condenses at a cooler spot (the anode, for example, whose focus temperature is much lower than the cathode temperature with most materials), and is here reduced to the metal again [9]). The oxygen liberated continues to attack more tungsten and makes the process progressive.

Water vapour might occur in the tube as the result of the liberation of hydrogen from metal parts and its oxidation by any oxide present; moreover, the glass may give off water vapour. A very rigorous outgassing and evacuation of the tube is therefore necessary. For this reason a getter is used in this tube, as in all "Metalix" tubes, which rapidly absorbs all gas freed during use. Due to these precautionary measures the intensity of the tungsten lines in the X-ray spectrum obtained amounts to only 1 to 2 per cent of that of the desired radiation after the tube has been in use for 1000 hours.

Moreover, a rigorous de-gassing is desirable for another reason: due to a process similar to the one described above, impurities also have an accelerating action on the evaporation of most of the anode metals, particularly on copper, so that the surface of the anode would become rough more rapidly if the tube were not well de-gassed.

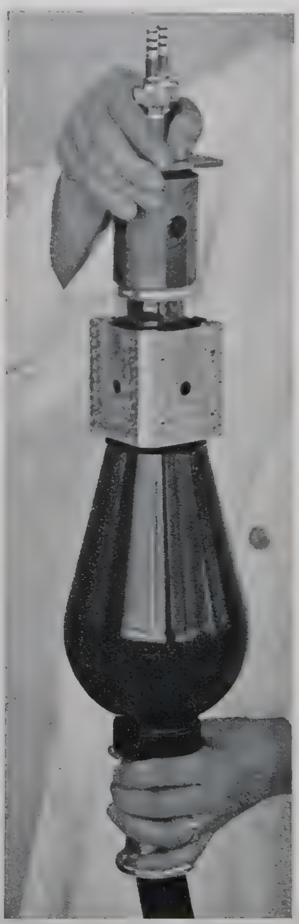

Fig. 11. Photograph of the X-ray tube. The tube is drawn partially out of its container.

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[9]) C. J. Smithells, Tungsten, 1936, p. 86.

Use of the tube

In conclusion we shall say a few words about the practical aspects of working with the tube described. The way in which complete protection is obtained against high tension and X-radiation ouside the active beam has already been discussed. The construction with a metal anode can makes it possible to place the lead jacket immediately around the can (with a glass tube the lead jacket must be at some distance from the wall as otherwise it would cause a distortion of the field and excessive local increases in the field strength). The lead jacket therefore need only be short and of small diameter, and the weight of the tube is therefore small. This has the advantage that one may work with light stands and simple suspension arrangements, and a fine adjustment on a definite point of the object such as is necessary in the measurement of stresses, is easily and quickly attained. The small size of the tube (see the photograph in *fig. 11*) also makes for ease in manipulation.

The characteristics mentioned are desirable in all X-ray tubes used in technical work. For crystal structure analysis moreover it is of advantage that the tube is quickly replaceable. It is sometimes necessary to change the type of radiation (*i.e.* the anode material), in order to adapt its wave length to the parameters of the crystal to be investigated. The tube described can be removed from its container by loosening two screws and may then be replaced by a tube with a different anode material. The water cooling system is taken out with the first tube and then transferred to the second. In this way the container remains dry.

A NEW FREQUENCY-CHANGING VALVE

by J. L. H. JONKER and A. J. W. M. VAN OVERBEEK. 621.385.5 : 621.386.694

An octode, *i.e.* a frequency changer and amplifier valve, is often used as frequency changer in superheterodyne receivers. The octode also serves as oscillator valve for generating the auxiliary frequency. In this article two objections to the use of an octode are discussed, namely the induction effect and the shift in the oscillator frequency when automatic volume control is employed. The induction effect may be neutralized in a simple way. In order to get rid of the frequency shift a new type of octode has been constructed in this laboratory in which the oscillator part and the frequency-changing part are practically independent of each other. The construction and characteristics of the new frequency changer are dealt with in detail.

Introduction

The transformation of the high-frequency oscillation into an intermediate-frequency oscillation which is applied in modern radio receiving sets is often obtained by means of an octode. This valve may be considered as a combination of a triode oscillator valve with a pentode amplifier valve, as is indicated in *fig. 1*. The oscillator, consisting of the cathode *k* and the grids *1* and *2* delivers a periodically varying current; as a result of this current the slope of the pentode changes, or in other words the degree to which the alternating voltage of the control grid *4* of the pentode acts upon the anode current. As one of the results of the action of grids *1* and *4* an alternating current component is obtained in the anode current, with a frequency equal to the difference between the oscillator frequency and the signal frequency on grid *4* which we shall call the signal grid.

This system of wave length transformation, when compared with other constructions in which separate valves are used for oscillator and fre-

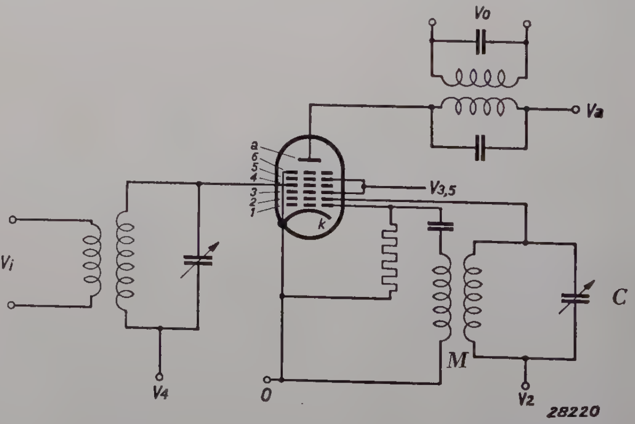

Fig. 1. Diagram of the principle of a frequency-changing stage when an octode is used. The cathode *k* with the grids *1* and *2* forms an oscillator triode; grids *4*, *5* and *6* form, with anode *a*. an amplifier and frequency-changing pentode. The screen grid *3* is the shield between these two parts of the octode; V_i is the input voltage and V_0 the output voltage.

quency-changing stages, has the advantage of simple construction and smaller current consumption, while a low oscillator voltage is sufficient to give a satisfactory ratio between high frequency and intermediate frequency. On the other hand there are several difficulties due to the reciprocal effects of the oscillator part and the amplifier part. The most important of these effects are the so-called induction effect and an effect on the oscillator frequency by the bias of the signal grid; the oscillator frequency varies, when for example automatic volume control is applied.

The induction effect has been discussed at length in an earlier number of this periodical [1]). This phenomenon consists in the fact that an alternating voltage of the oscillator grid *1* is induced on the signal grid *4* by the electrons which pass from grid *1* to grid *2*. This may result in the oscillator voltage also being conducted to the aerial which then radiates energy. Moreover, due to this voltage a direct current may flow to grid *1* and the amplification may be unfavourably affected.

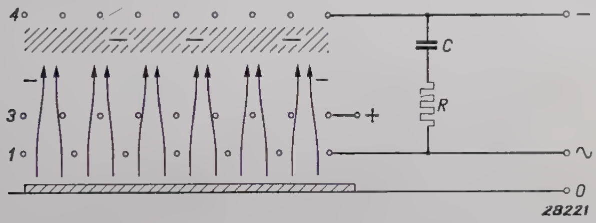

Fig. 2. Diagrammatic representation of the occurrence of the induction effect. When the voltage of grid *1* varies, the space charge due to the electrons which pass this grid and turn back in front of grid *4* also varies. As a result an alternating charge is induced on grid *4*. The induction effect may be compensated by a neutralising condenser *C* with a resistance *R* in series.

Let us assume that grid *4* (see *fig. 2*) is at a negative potential, while the voltage of grid *1* is variable. The electrons which pass grid *1* will turn back at a definite plane in front of grid *4*; in the neighbourhood of this plane a strong negative space charge is formed which induces a positive charge on grid *4*. When the voltage of grid *1* now increases the space charge increases and therefore also the charge on grid *4*. On the other side of grid *4*, in the circuit of fig. 2, a negative charge is induced on that plate of the neutralising condenser *C* which is connected with grid *4*. The induction effect thus acts in the opposite way to the condenser and can be described by a negative capacity between grids *1* and *4*. By choosing a suitable value of the capacity *C* it may therefore be arranged that the only result of the rise and fall of the voltage of grid *1* is a passage of charge back and forth between grid *4* and the condenser plate connected with it, without any flow of current in the external circuit of grid *4*. The "negative capacity" of the induction effect is then neutralized by the positive capacity in parallel with it. This neutralization will, however, in general only be complete for a certain working point of the valve.

Actually the formation of the space charge in front of grid *4* occurs with a slight delay with respect to the voltage variations of grid *1* due to the transition time of the electrons. This delay may be taken into account be causing the charging of the neutralising condenser *C* to occur with a lag. This can be done by means of a suitably chosen series resistance *R*. In this way the induction effect may be so much reduced that it is no longer objectionable in practice.

The second difficulty mentioned above is an influence on the oscillator frequency by the bias of grid *4*. This may be explained as follows. Part of the electrons pass the signal grid with a low speed and the rest are reflected. Electrons may be reflected back and forth between grids *1* and *4* several times. They will finally be captured by the oscillator anode *2* or the first screen grid *3*, or they will escape between the meshes of signal grid *4*. The average number of reflections in an octode of the type EK 2 is two or three. The result of these repeated reflections is a considerable increase of the space charge in the neighbourhood of grids *1* and *2* (by which their capacity is increased) and an effect on the current-voltage characteristics of the oscillator triode part. If for example the negative bias of the signal grid is increased, the percentage of reflected electrons increases, and therefore also the space charge in the neighbourhood of grids *1* and *2*. The capacity of these grids is thereby increased, while in addition the current to grid *2* and consequently the slope of the oscillator triode changes. Both effects have an influence on the oscillator frequency [2]).

In this connection it is important to note that due to the increase in the space charge by reflected electrons the induction effect is also considerably increased. Apart from these undesired effects, the increase in the space charge also has an advantage: because of the repeated reflections in which each electron is given several opportunities to pass or to be reflected, the slope of the anode current as a function of the voltage on the signal grid is increased.

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[1]) Some characteristics of receiving valves in short-wave reception, Philips techn. Rev. **1**, 171, 1936.

[2]) The influence of the capacity of grids *1* and *2* on the oscillator frequency may be deduced from fig. 1. The capacity of grid *2* is connected directly, that of grid *1 via* the mutual induction *M* in parallel with the capacity *C* of the oscillator circuit. An increase therefore causes a lowering of the resonant frequency. The influence of the slope on the oscillator frequency is explained fully in the article: The Behaviour of Amplifier Valves at High Frequencies, Philips techn. Rev. **3**, 103, 1938 (*cf.* pp. 106 - 108).

In order to meet the objections to the octode discussed above, a modified type of octode was constructed in this laboratory, in which the electrons reflected at the signal grid are prevented from reaching the oscillator part. The frequency shift is thereby practically completely eliminated and the induction effect is considerably reduced. On the other hand the reflected electrons can no longer be utilized to increase the slope of the signal grid. The new construction, however, as we shall see later, offers new possibilities of increasing this slope, so that the slope of the new octode is actually even slightly greater than that of the old type.

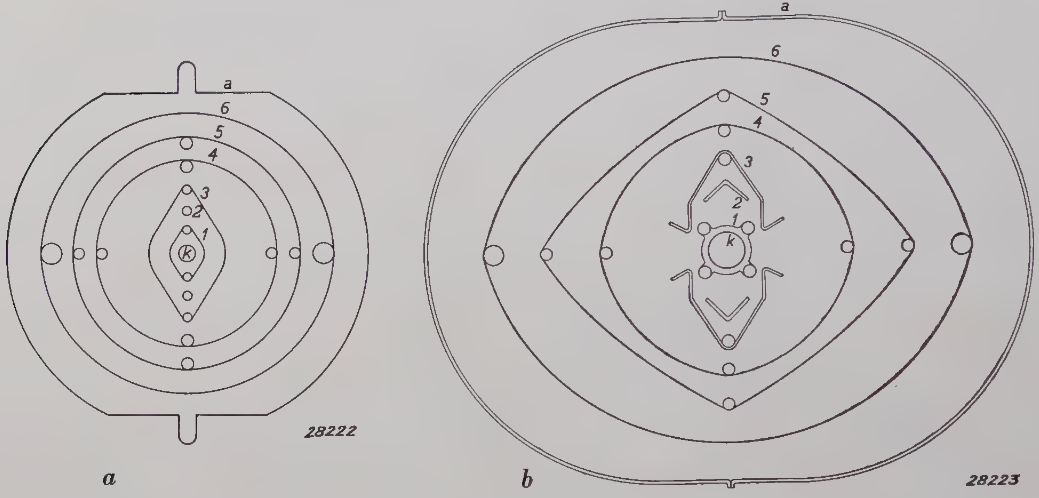

Fig. 3*a*. Arrangement of the electrodes in the octode type EK 2. *k* cathode, *1* oscillator anode, *3* first screen grid, *4* signal grid, *5* second screen grid, *6* suppressor grid, *a* anode.

b) Arrangement of the electrodes in the four-beam octode, type EK 3. *k* cathode, oscillator grid, *2* oscillator anode, *3* screen grid, *4* signal grid, *5* screen grid, *6* suppressor grid, *a* anode.

The four-beam octode

The above considerations have shown that if the frequency shift upon regulation of the bias of the signal grid is to be avoided, the octode must satisfy the following two requirements: firstly the anode current of the oscillator part and secondly the capacities of the oscillator electrodes must be independent of the voltage of the second control grid.

The functioning of the oscillator part will only be independent of the action of the pentode part of the valve, if the paths of the electrons in the two parts are entirely separate. This was accomplished by dividing the electron current emitted from the cathode into four separate beams, two of which are directed to the oscillator part and two to the pentode part.

The oscillator part

Fig. 3b represents the construction of the four-beam octode (for the sake of comparison *fig. 3a* shows the construction of an ordinary type of octode, type EK 2). The oscillator grid *1* is circular like the cross section of the cathode *k*. By attaching four supports to this grid, four sharply separated beams are obtained. Grid *2*, the oscillator anode, is replaced by two plates which intercept two of the beams. The screen grid is formed by the two screens *3* which are kept at a positive potential of about 100 volts with respect to the cathode. Both parts of the valve in which the oscillator current flows are in this way practically shut off from the rest of the valve.

Two small slits between the two halves of the screen grid *3* have been left open for the other two beams which are directed toward the pentode part of the valve. A current thus passes out through these slits whose intensity is dependent on the voltage on the oscillator grid. The electrons which move through the slit to the signal grid *4* are attracted by the projecting edges of the positive screen, so that they are deflected and form a fan-shaped electron beam. If an electron is reflected by the signal grid, and if its deflection is sufficiently great, it will no longer reach its starting point but be captured by the positive screen *3*. Reflected electrons therefore are no longer able to reach the neighbourhood of the oscillator grid, and in this way they are prevented from exercising any influence as a capacity on that grid.

Fig. 4 shows the paths described by the electrons in the space between grids *3* and *4*. By choosing a suitable form for the screen grid *3* and the signal grid *4*, electrons which pass through the slit only slightly to one side of its centre line may be deflected sufficiently so that they are no longer reflected to the slit. The electrons which pass through the slit at practically its centre line, and would otherwise be insufficiently deflected, are scattered by the support of the signal grid *4* (see fig. 3*b*), so that only a very small part of these electrons can be reflected back to the oscillator part.

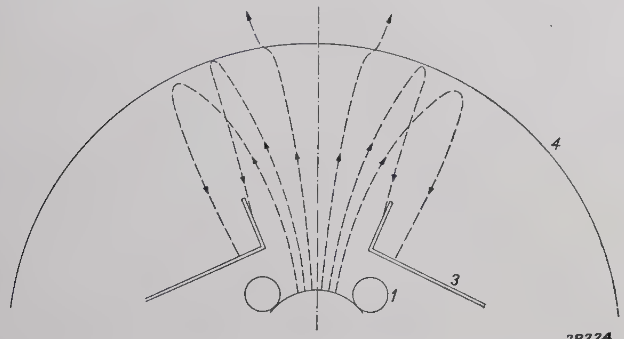

Fig. 4. Path of the electrons between the screen grid *3* and the signal grid *4* of the four-beam octode. The slightly deflected electrons pass grid *4*, while the strongly deflected electrons are reflected.

The slope of the pentode section

As was stated above, it was to be expected that the slope of the pentode part would be less with the new type of construction than in the earlier form. It was therefore important to devote attention to the various other factors which influence the slope favourably.

Upon a closer consideration of the paths of the electrons in fig. 4 it will be seen that the least deflected electrons in the case represented by the figure pass grid *4*, while the strongly deflected electrons turn back at a clearly visible distance in front of grid *4*. This was to be expected, because with increasing deflection a larger and larger part of the energy of the electrons is used in motion parallel to the plane of the signal grid, so that a smaller and smaller part of the energy remains available to overcome the potential difference between the screen grid *3* and the signal grid *4*.

With increasing voltage on the signal grid, therefore, a larger and larger part of the electron beam is allowed to pass. The slope will now be greater, the smaller the voltage interval between the grid voltage, at which the centre of the beam can just pass grid *4*, and the voltage at which the whole beam is allowed to pass.

In order to increase the slope it would now seem obvious to give grid *4* such a form that even in the case of the deflected electrons there is no motion parallel to the signal grid, so that all the electrons have the same amount of energy available to overcome the potential difference between screen grids and signal grid. This is actually possible as is shown in *fig*. 5. The electrons move perpendicular to the surface of the grid and are all reflected at the same very small distance from it. At a somewhat higher "critical" value of the grid voltage all the electrons would just be allowed to pass and the slope of the theoretical model at this value of the signal grid voltage would be infinite. Actually the slope is of course limited, in the first place because the electrons do not all have exactly the same energy, since they leave the cathode with different initial velocities (thermal motion), secondly because the distribution of potential over the surface of the signal grid is not uniform, but the potential between the wires of the grid is higher than that close to the wires, and thirdly because the reciprocal action of the electrons (space charge) has been neglected in the model. In spite of these deviations a maximum slope of the actual valve will correspond to the infinite slope of the model.

This method of obtaining a steep slope has, however, one serious objection: because the electrons are normally reflected they move along the paths on their return journey, as may be seen in fig. 5, so that they return again to their starting point, the slit, and the deflection does not have the desired effect. The tangential motion is therefore essential in order to lead the reflected electrons away from the slit.

Because of this the problem was solved in a different way, namely by altering, not the form of the signal grid, but the distribution of potential over the surface of the grid. It is possible to do this, since this potential does not depend only upon the signal grid voltage itself, but also upon the voltage and the distance of the screen grid 5

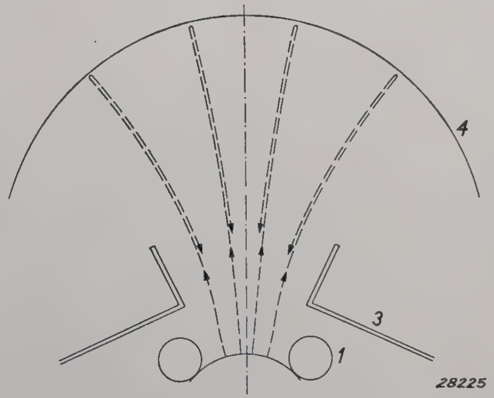

Fig. 5. Path of the electrons in the four-beam octode, when the signal grid has such a form that it is struck perpendicularly by the electrons. The electrons are reflected to the slit and are not captured by the screen grid.

lying behind it. As may be seen from fig. 3*b* this screen grid approaches the signal grid more and more closely with increasing distance from the middle of the slit, so that the effective potential is higher at the point where the strongly deflected electrons reach the signal grid than in the neighbourhood of the middle line. Therefore the strongly deflected electrons, which have less energy available to overcome the potential difference, have a weaker opposing field to overcome.

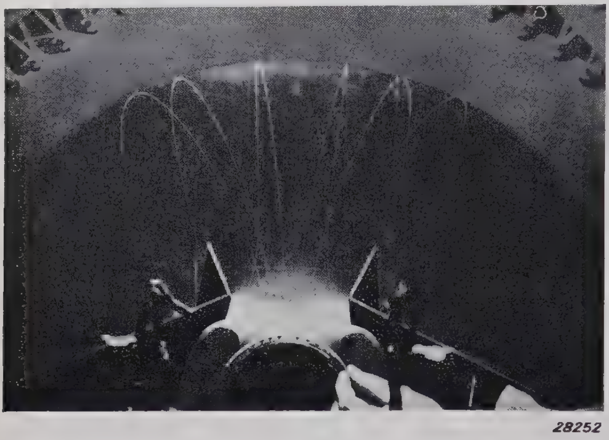

Fig. 6. Photograph of the path of the electrons taken with a model of a four-beam octode with "adjusted" potential distribution over the signal grid. As in fig. 5 with the same critical voltage the electrons can just reach grid *4*; they are not, however, reflected back to the slit but are scattered and captured by the screening electrode *3*.

The distribution of potential may now be so chosen that the "critical" control grid voltage is the same at all points of the grid. *Fig. 6* is a photograph of the paths of the electrons which are then obtained. This photograph was made with the help of the mechanical model described earlier in this periodical [3]). The electrons have very different tangential velocity components, nevertheless they all just reach the plane of the control grid, turn back and are then captured by the screen.

In *fig. 7* the current distribution over the anode of a valve is represented with varying potential at the signal grid, and compared with that of a valve in which the potential in the plane of the signal grid was constant. The distance between two successive curves is a measure of the slope. This figure demonstrates well that the control grid voltage at which the greatest slope is attained in the last case varies over the anode and that it increases with increasing deflection of the electrons. In the valve with adjusted potential distribution this is not the case. Moreover with an adjusted potential distribution the current density over the anode is fairly constant up to angles of deflection of 50°, except for angles smaller than 25° where the anode is very much screened by the previously mentioned support on grid *4*.

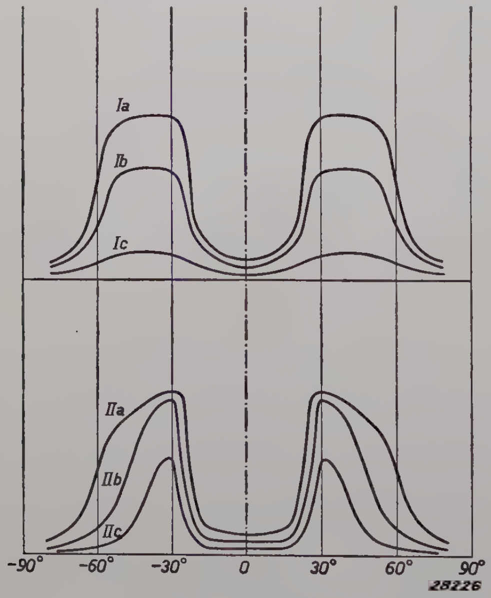

Fig. 7. Current distribution over the anode of the four-beam octode.

I the potential in the plane of grid *4* is adjusted to the speed of the electrons,
II the potential is not adjusted.
a voltage of the signal grid is 0 volts
b ,, ,, ,, ,, ,, ,, —2 volts
c ,, ,, ,, ,, ,, ,, —3.5 volts

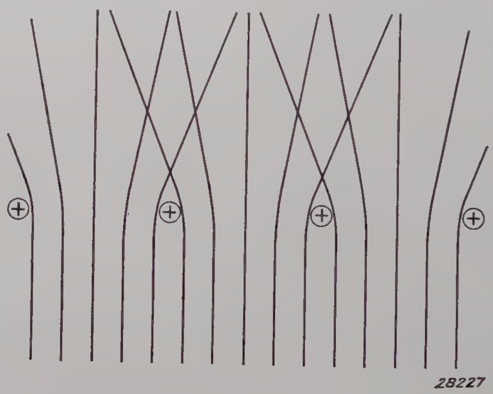

Fig. 8. Deflection of the electrons at a grid with positive potential. Behind the grid the electrons move in criss-cross directions.

The construction of screen grid *3* with slits is an important factor governing the adjusting of the potential distribution along the signal grid. If a wire mesh grid were used instead of the screen grid the electrons would also be deflected, and would arrive on the signal grid with different speeds. The deflected electrons would, however, move in criss-cross directions (see *fig. 8*) with the result that at every point on the signal grid electrons with different perpendicular components of velocity would arrive, so that it would no longer be possible to determine for every point a certain unique value of the critical potential.

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[3]) Philips techn. Rev. **2**, 338, 1937.

Characteristic properties of the four-beam octode

In *fig. 9* the current to the oscillator anode *2* of the four-beam octode is represented as a function of the voltage of the signal grid *4*. It may be seen that the oscillator current is entirely independent of the grid voltage in the pentode part, in contrast to the dotted line representing the oscillator anode current of the octode type EK 2.

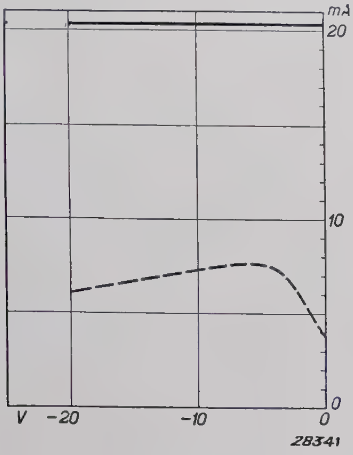

Fig. 9. Current of the oscillator anode *2* as a function of the voltage of the signal grid *4*. Full line: four-beam octode, dotted line: EK 2 octode.

In *fig. 10* is shown the change in the capacity of the oscillator grid with respect to the other electrodes as a function of the voltage of the signal grid. Here also the full line refers to the four-beam octode and the dotted line to the EK 2 octode. It may be seen that the variation in capacity is reduced to about one fourth.

The two causes of oscillator frequency shift have therefore been adequately eliminated in the four-beam octode. In other respects also the oscillator part has been considerably improved.

In the first place the slope has been considerably increased, in the second place the transition time of the electrons from the cathode to the oscillator anode has been shortened, since the electrons can follow a straight path which was impossible in the earlier construction as shewn in fig. 3*a*, where the supporting rod of grid *1* stood in the way.

Due to the greater slope the back coupling is more intense when the same coils are used, so that with fewer turns on the coil a sufficiently high oscillator voltage can be obtained. The minimum capacity of the oscillating circuit therefore becomes smaller, so that the ratio between the longest and the shortest wave length of a band which can be compassed with a given condenser range becomes greater. Furthermore, especially in the short-wave region, the frequency change upon fluctuations in the mains voltage is smaller because, due to the shortening of the transition times of the electrons, the effect of these times on the oscillator frequency is less.

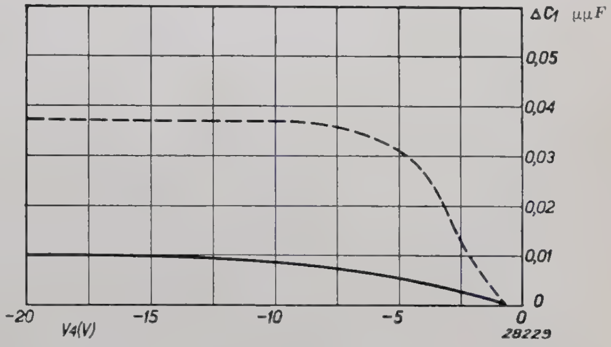

Fig. 10. Change in the capacity of the oscillator grid as a function of the voltage of the signal grid. Full line: four-beam octode, dotted line: EK 2 octode.

Since the space charge between the two grids *1* and *4* is less, the induction effect will also be present to a smaller degree, as mentioned above, while the remainder of the effect can be still further diminished by connecting these grids by means of a condenser and resistance in series.

LOW-PRESSURE MERCURY DISCHARGE WITHIN A LUMINESCENT TUBE

by W. UYTERHOEVEN and G. ZECHER. 537.525.8 : 621.327.3 : 537.37

Column discharges in mercury at low pressure, due to the strong ultraviolet resonance line 2537 Å, are particularly suitable for excitation of the luminescence of zinc silicate and other phosphorescent substances. The process of this light excitation is discussed in this article, as well as the various factors which determine the efficiency. The following also are dealt with: the use of phosphorescent substances in order to improve the efficiency and colour and for the purpose of rendering alternating current discharges free of flicker.

In the discussion in a previous article [1]) on the light emission in the positive column several cases were dealt with in which a considerable portion of the electrical energy supplied was transformed directly into visible light by excitation of favourably situated levels. In addition to the visible spectral lines, however, there are practically always other lines also which lie in the ultraviolet or infrared part of the spectrum, and which therefore do not contribute directly to the light flux. Attempts have been made to utilize this invisible radiation, and success has been attained in the case of the ultraviolet part by the use of luminescent substances. When these substances are exposed to radiation of certain wave lengths in the ultraviolet, they emit radiation in another region with longer wave lengths in the visible. Luminescent substances thus act as transformers of radiation. with the limitation that the wave length of the radiation is practically always increased in the transformation (Stokes' law). In this way it is possible to improve considerably the efficiency of certain discharges.

It has been found that the production of ultraviolet radiation and its transformation into visible light can take place in such a way that discharges which themselves emit almost no light can be made very efficient sources of light. As an example we shall discuss the low-pressure mercury discharge within luminescent boundary, confining our discussion to the column itself. Various factors, such as ignition and connections, which are very important when these discharges are used in lamps, will not be considered here, since they have no direct effect on the physical phenomena which occur in the column with a fluorescent wall.

Luminescent substances

The phenomenon of luminescence and the properties of various substances which exhibit this phenomenon, have been recently described in this periodical [2, 3]). We shall confine ourselves here to those substances which are used as light transformers in the low-pressure positive column of the mercury discharge. We are then chiefly concerned with "impurity luminophores" and "fluorescent glass". A typical impurity luminophore is zinc silicate. The zinc silicate is in this case the base material, which upon being mixed with small amounts of an "activator", manganese for example, and after a certain treatment, acts as a luminescent substance. The treatment consists mainly in a crystallization by heating to a high temperature. *Fig. 1* shows the emission curves for several zinc beryllium silicates activated with manganese in a low-pressure mercury discharge, in which the radiated energy is plotted as a function of the wave length; the maximum is put equal to 100. It may be seen that the emission takes place over a wide range of wave lengths, which is of great advantage for many purposes. In order to determine from these curves the (relative) light emission curves it is only necessary to multiply the ordinates

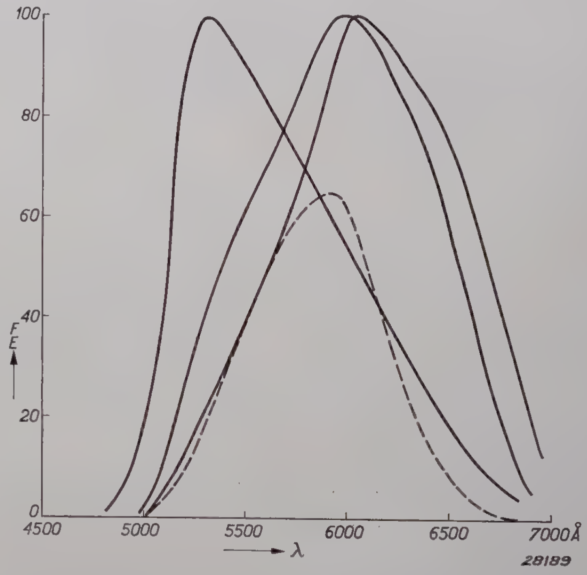

Fig. 1. Emission curves: energy as a function of wave length (full lines; maximum put equal to 100), for several zinc beryllium silicates activated with manganese in a low-pressure mercury discharge. The dotted line gives the light intensity as a function of wave length for the phosphorescent substance with its energy maximum at 6050 Å. At the wave length of maximum eye sensitivity the light intensity is put equal to the energy.

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[1]) W. Uyterhoeven, Philips techn. Rev. **3**, 201, 1938.

[2]) W. de Groot, Philips techn. Rev. **3**, 125, 1938.

[3]) J. H. Gisolf and W. de Groot, Philips techn. Rev. **3**, 245, 1938.

by the corresponding values of the relative sensitivity of the eye, as has been done for the curve with the maximum at 6050 Å (dotted line in fig. 1).

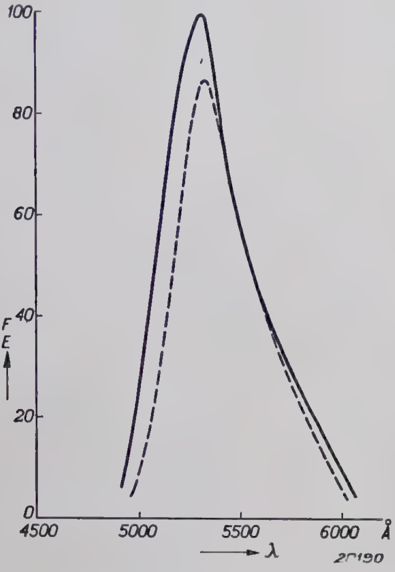

Fig. 2. Emission curves: energy (full line; maximum put equal to 100) and light (dotted line) as functions of the wave length for uranium glass irradiated with the light of a low-pressure mercury discharge.

A typical luminescent glass is uranium glass, in which certain groups of molecules of the added uranium compound are luminescent. In *fig. 2* may be seen the relative emission curves as a function of the wave length for uranium glass in a low-pressure mercury discharge. For further details we refer to the publications already mentioned. Other substances, such as copper and tin compounds, when added to glass can make it strongly fluorescent.

The production of light in luminescent column discharges

The production of visible light in positive columns with fluorescent substances is a rather complicated process in which we can distinguish several successive steps. In the first place there is the production of the ultraviolet radiation in the discharge, then the absorption of this radiation by the luminescent layer, which after a longer or a shorter time emits a part of the energy absorbed as visible light. In each of these steps in the transformation of the electrical energy supplied to the discharge into visible light, there will in general be a certain loss. It has, however, been found that an extraordinarily good efficiency can be attained, which, expressed in the usual way in lumens emitted per watt supplied, may reach 100 lumens per watt. We shall now study how this high efficiency is achieved.

The first step in the process of light excitation is the production of ultraviolet radiation, which, in the low-pressure mercury discharge, consists mainly of the resonance line 2537 Å (partially also of the resonance line 1850 Å).

In *fig. 3* is given the relative distribution of energy for a typical mercury discharge at low pressure, in which, in addition to the line 2537 Å, the intensity of which is taken as 100, several lines with longer wave lengths are also indicated. In order to obtain good efficiency in the production of the resonance line, the discharge will be made to occur preferably at a low current density. One of the results of this is that the energy taken up per cm of length is small (and therefore also the light flux produced), and the tube has a low brightness. A lamp with luminescence excited by the ultraviolet radiation of the low-pressure mercury discharge will therefore be made chiefly in relatively small units of, for instance, 25 watts. With a suitable choice of the mercury vapour pressure (*i.e.* the temperature), the tube diameter, and discharge current it is possible to transform about one half of the electric energy supplied per cm length of tube into radiation with a wave length of 2537 Å. If it is desired to excite luminescence by means of radiation in the near ultraviolet, for instance in the neighbourhood of 3600 Å, it is better to use a mercury discharge with high or very high pressure. For these lines as well as for the visible mercury lines, the considerations discussed in the article mentioned previously ¹) are valid. According to these considerations high pressure and current density are necessary for economical production of lines of longer wave length.

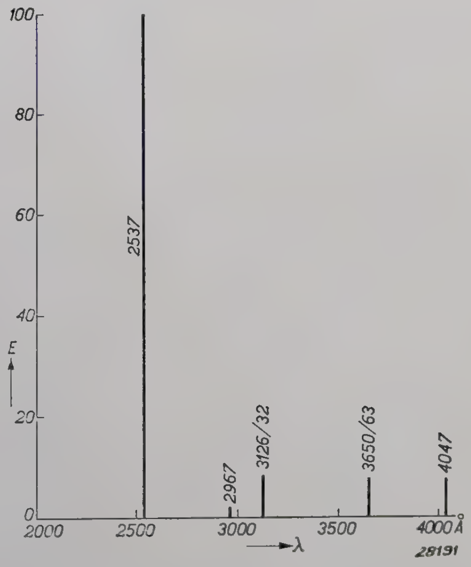

Fig. 3. Relative energy distribution of a typical low-pressure mercury discharge; intensity of the line 2537 Å set equal to 100.

In order that all the ultraviolet radiation may be used, it must all be absorbed by the luminescent layer, which may therefore not be too thin. It is, however, not always possible to use a sufficiently thick layer since such a thick layer may offer difficulties by not adhering to the inner wall. It may also happen that the phosphorescent substance absorbs too much of its own radiation so that light is lost. In these cases it is possible to use a thin layer of luminescent material and, instead of ordinary glass, a fluorescent glass; the ultraviolet radiation which is not absorbed by the phosphorescent substance is then transformed into visible radiation in the glass.

Efficiency of luminescence

There are various ways of defining the efficiency in the transformation of the ultraviolet radiation absorbed by the phosphorescent substance into visible light. One may determine how many quanta of visible light are emitted per 100 quanta of ultraviolet light absorbed. If the result is 80 for instance, the "quantum efficiency" is 80 per cent. Such values actually occur, and even values up to 100 per cent.

Even when the quantum efficiency is 100 per cent, the ratio of the energy radiated as visible light to the energy absorbed as ultraviolet light, the "energy efficiency", is considerably less than unity. If for every ultraviolet quantum with the frequency ν_1, one visible quantum with the frequency ν_2 is produced, where $\nu_2 < \nu_1$, the energy ratio is $h\nu_2/h\nu_1 = \nu_2/\nu_1$, since according to Planck's formula the energy of a quantum of radiation with the frequency ν is $h\nu$. Since the wave length is inversely proportional to the frequency the energy efficiency is $\nu_2/\nu_1 = \lambda_1/\lambda_2$. Thus when the wave length absorbed (λ_1) is 2537 Å and the wave length emitted (λ_2) is 5550 Å the energy efficiency is $\lambda_1/\lambda_2 = 2537/5550 = 0.46$.

If it is desired to express the efficiency in lumens per watt, the position and shape of the emission curve of the energy with respect to the eye sensitivity curve must be taken into account. The highest yield of light with a given energy efficiency is obtained with a narrow emission curve which has a maximum in the neighbourhood of the wave length $\lambda = 5550$ Å of maximum eye sensitivity. The colour of the light emitted by the phosphorescent substance is then a pronounced green which may be undesirable for some purposes.

The following example in figures may give some idea of the results attainable with the phosphorescent substances now used. We assume that 50 per cent of the electrical energy used in the column is transformed into radiation of the wave length 2537 Å, that the quantum efficiency is one, and the energy efficiency is 50/100 [4]), and that for each watt radiated in the visible 200 lumens are obtained. We then find for the total efficiency of the transformation: $\frac{50}{100} \cdot 1 \cdot \frac{50}{100} \cdot 200 =$ $= 50$ lumens per watt.

Adaptation of the discharge to the luminescent substance

In principle it is possible to find for a given phosphorescent substance a discharge, the emission of which in the ultraviolet has a favourable position with respect to the absorption spectrum of the phosphorescent substance. Such a substance absorbs mainly the wave lengths in a certain region several hundred Ångstrom units wide, in which region the absorption has a maximum. *Fig. 4* shows schematically the absorption spectrum of a zinc beryllium silicate. The maximum is considered to be 100. It may be seen that maximum absorption occurs in the neighbourhood of the line 2537 Å, which may be of advantage since the luminescent layer can have a minimum thickness when this wave length is used. In the case of the silicates and tungstates, activated with metals or not, it may in general be said that their absorption region in the ultraviolet lies at wave lengths shorter than 3000 Å. For these substances therefore the mercury discharge at

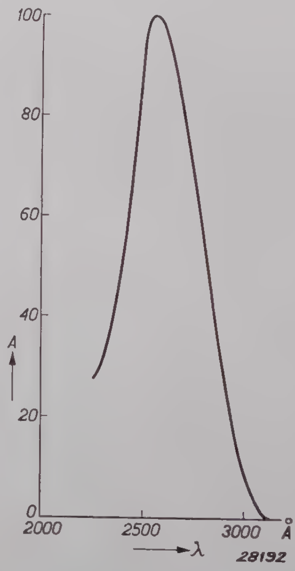

Fig. 4. Schematic representation of the absorption curve for a zinc beryllium silicate, maximum put equal to 100.

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[4]) In an accurate calculation it must be taken into account that the energy efficiency λ_1/λ_2 is not the same for all wave lengths λ_2 of the emission band.

low pressure with the strong line at 2537 Å is the most suitable source of radiation for the excitation of light. Phosphorescent substances in which the basic material is a sulphide, for example the green phosphorescent zinc sulphide activated with copper, are, however, best rendered phosphorescent by irradiation with ultraviolet light of long wave length (3600 Å). For this purpose the mercury discharges at high and very high pressure are the best sources of radiation, since they have very strong emission lines in the neighbourhood of 3600 Å.

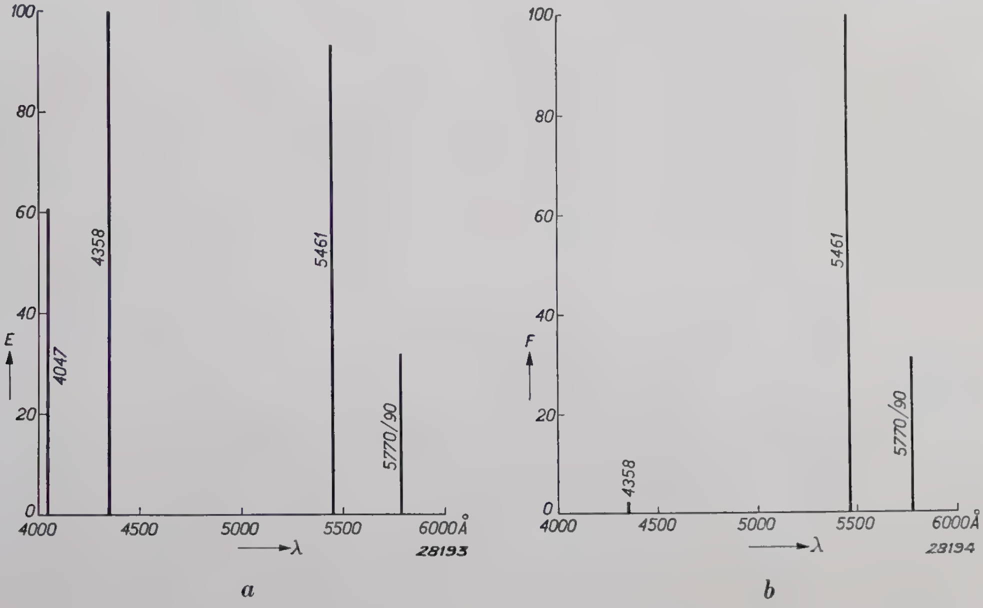

Fig. 5. Visible spectrum of the mercury discharge at low pressure: *a*) relative energy distribution, *b*) relative light emission, maximum put equal to 100.

In practice, however, we begin with a given discharge, and try to find a phosphorescent substance which is suitable. In doing this we may have different purposes in view: either improvement of the efficiency or improvement of the colour. In the first case the conditions which the luminescent substance must satisfy are obvious from the above discussion. The maximum in the absorption curve of the substance must lie in the neighbourhood of the maximum of the ultraviolet emission of the source of radiation, with low-pressure mercury discharges therefore in the neighbourhood of 2537 Å. The emission curve of the phosphorescent substance, which must have as high a quantum efficiency as possible, must have its maximum in the neighbourhood of maximum eye sensitivity (at $\lambda = 5550$ Å). In this way a very high efficiency is obtained, as high as 100 lumens per watt, but strongly coloured (green) sources of light are also obtained. This is not a great objection for a number of purposes (for outdoor illumination, for instance). For illuminated advertising signs attempts are even expressly made to obtain various colours. For interior illumination, however, a colour reproduction more or less true to nature is indispensable, even if it is obtained at the cost of efficiency. In this case the adaptation of the phosphorescent substance to the discharge will therefore consist in the fact that the light emission of the discharge together with that of the phosphorescent substance must give a mixed light with which the observation of colours is satisfactorily true to nature.

In *fig.* 5, *a* and *b*, may be seen the composition of the visible spectrum of the mercury discharge at low pressure, in fig. 5*a* the relative energy distribution and in fig. 5*b* the relative light emission. The influence of the low eye sensitivity at the extremities of the spectrum may be clearly seen upon comparing the two diagrams: with respect to energy the blue line 4538 Å is the strongest, with respect to light the green line 5461 Å is strongest.

Block method of colour determination [5]

In the development of sources of light consisting of a positive column discharge with a fluorescent boundary, the socalled "block method" for the determination of colour is very useful. Since the measurement of complete emission curves is a fairly elaborate procedure, these curves have been replaced by a kind of block diagrams. The whole region of the visible spectrum is divided into eight blocks limited by the following wave lengths: 4000 - 4200 - 4400 - 4600 - 5100 - 5600 - 6100 - 6600 - 7200 Å. A spectrum of the light source to be investigated is thrown on a photocell by means of a double monochromator. In the path of the light rays various diaphragms are placed, each of which passes only the wave lengths which belong in one of the eight blocks. By a suitable choice of the height of each diaphragm, the deviation of galvanometer or electrometer due to the current of the photocell may be made proportional to the light flux emitted in each block, whereby the eye sensitivity and the spectral sensitivity of the photocell are taken into account. By means of a light source with a known energy distribution, a tungsten lamp for instance, the installation may be calibrated.

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[5] For the block method see Philips techn. Rev. **2**, 1, 1937. The limiting wave lengths have been changed somewhat since that article was written, so that the mercury lines fall about in the middle of the blocks, which improves the accuracy of the method.

In *fig. 6* the block diagrams determined by this method are given for several cases. Fig. 6*a* represents the light emission of a low-pressure mercury discharge; it may be compared with fig. 5*b*. It may clearly be seen on the block diagram that the light flux is greatest in the green (5100 - 5600 Å), that there is, however, also a quite appreciable amount in the yellow region (5600 - 6100 Å) and in the blue (4200 - 4400 Å). Next to this in fig. 6*b* may be seen block diagrams for the radiation of two phosphorescent substances (without mercury light), namely zinc silicate (*I*) and zinc beryllium silicate

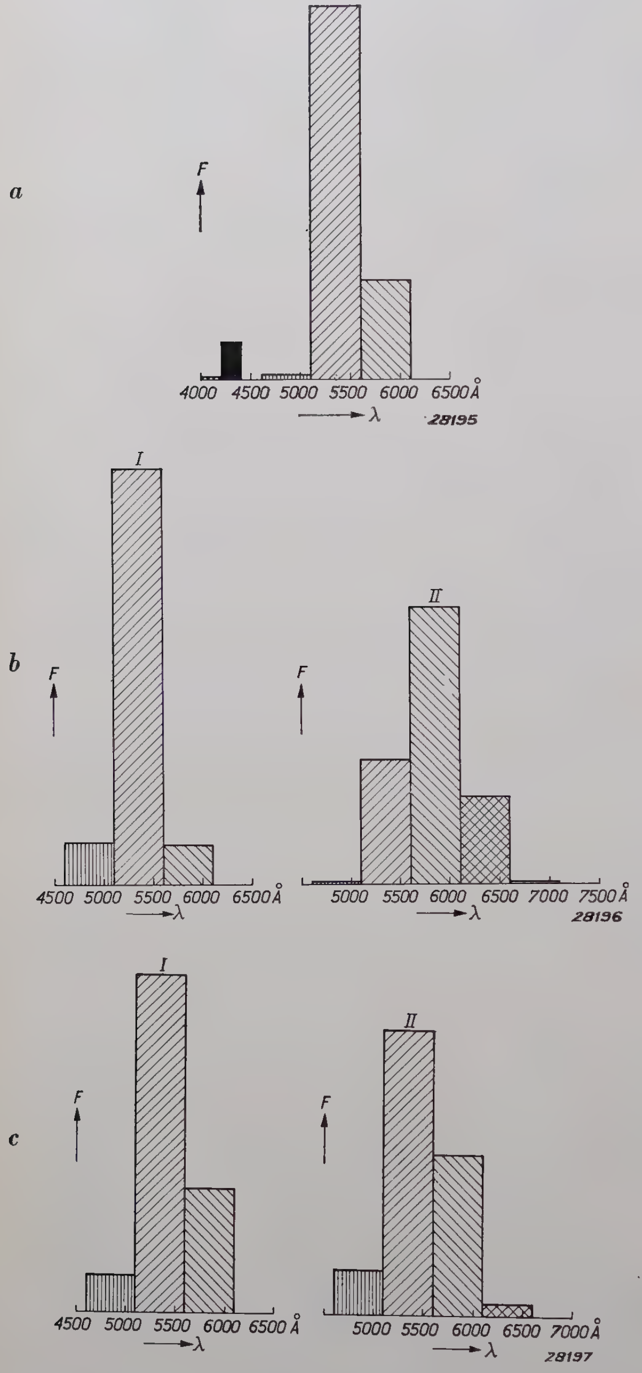

Fig. 6. Block diagrams of the light emission for *a*) a low-pressure mercury discharge *b*) two phosphorescent substances: zinc silicate (*I*) and zinc beryllium silicate (*II*), *c*) two luminescent glasses: uranium glass (*I*) and a combination of copper and uranium glass (*II*).

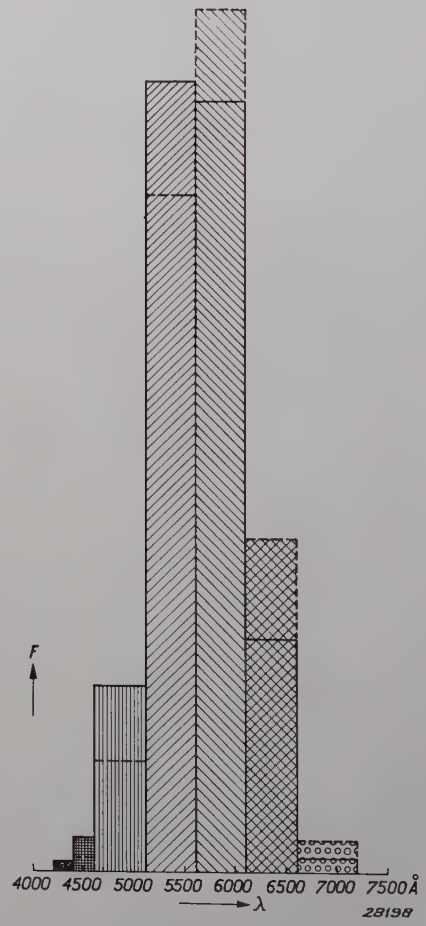

Fig. 7. Block diagram for sunlight (full line) and electric light, Bi-Arlita lamp type 78 W (dotted line).

(*II*), and in fig. 6*c* for the radiation of two phosphorescent glasses, namely uranium glass (*I*) and a combination of copper glass with uranium glass (*II*).

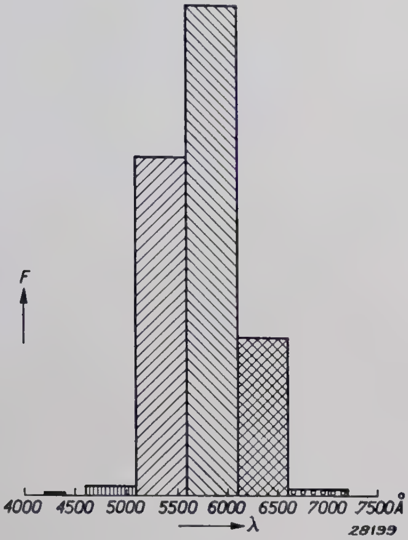

Fig. 8. Block diagram of the light of a mercury tube made of copper-uranium glass and containing zinc beryllium silicate.

The block diagram is very useful, particularly in judging the results of combining different luminescent substances. If one has as object the construction of a source of light which shall resemble sunlight or ordinary electric light for example, one begins by making the block diagram of these sources of light as is indicated in *fig. 7*. In the various experiments it is now possible in each case to find out whether the composition of the light satisfies the necessary requirements, and in which region any deficiency or excess occurs. If, for example, the dotted line of fig. 7 is compared with the diagram for zinc beryllium silicate of fig. 6*b*, it may be seen that the emission of the substance without the mercury spectrum resembles ordinary electric light fairly well. In this case the mercury light itself contributes only 15 per cent to the total light flux, so that the colour is practically determined by the phosphorescent substance. The combination of the light of the phosphorescent substance, glass and mercury discharge, as produced by a lamp for practical uses is finally given in *fig. 8*.

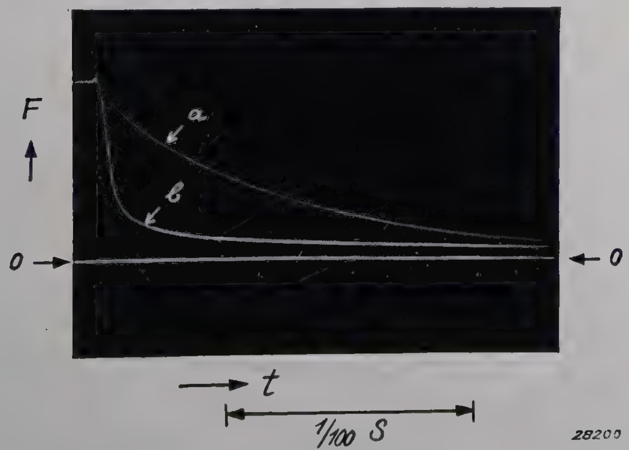

Fig. 9. Variation of the light intensity after interruption of the irradiation with ultraviolet light: *a*) for a phosphorescent silicate, *b*) for a phosphorescent sulphide.

Alternating current light sources rendered free of flicker

In the foregoing we have only discussed the property of luminescent substances known as "light transformation". At the same time a number of these substances may also act as "light accumulators", *i.e.* they luminesce not only while they are being irradiated, but they continue to emit light for some time after the irradiation has been interrupted. The phosphorescent substance is therefore able to store the energy for some time and then emit it gradually. The time during which the phosphorescent substance continues to luminesce varies very much from one substance to another. *Fig. 9* gives the course of

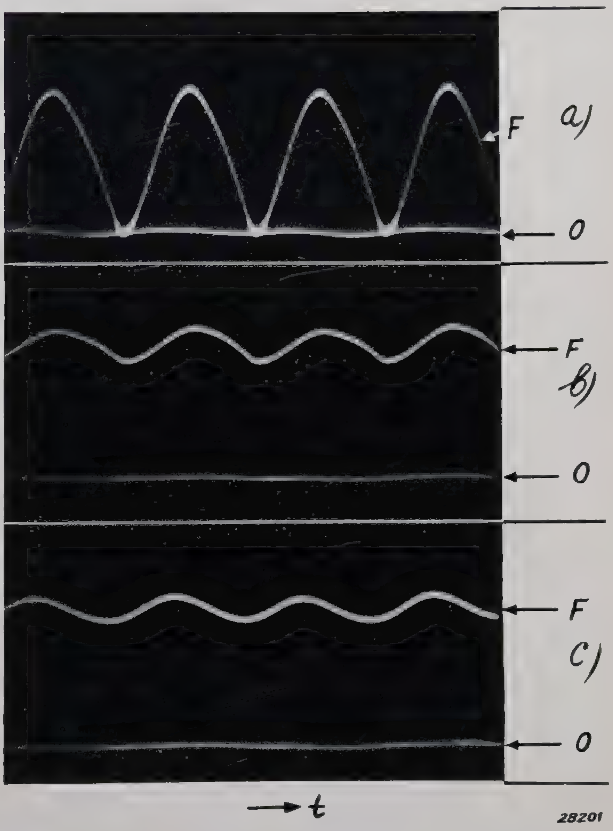

Fig. 10. Light variation with alternating current (50 c/s): *a*) mercury discharge at low pressure, *b*) low-pressure mercury discharge with phosphorescent cadmium silicate, *c*) gas-filled electric lamp (Bi-Arlita type 78 W).

the light emission after interruption of the irradiation for two types of substances: silicates (*a*) and sulphides (*b*). The silicates especially possess this property; tungstates on the other hand are practically without it.

The phenomenon of phosphorescence of these substances may be used to reduce the flicker with alternating current lamps. When the direction of the current is reversed, the current is zero for a short time, and practically no atoms are excited, so that the light emission becomes zero, since the phosphorescence of the discharge itself may usually be neglected. *Fig. 10a* shows the variation of the light with time in a low-pressure mercury discharge. In each half period the curve has practically the form of a sine curve in which the moments when the light is zero correspond to those when the current passes through zero. This periodic variation of the light intensity may be very disturbing in certain cases, especially in interior illumination. If the variation of the light from a low-pressure mercury discharge the boundary of which is covered with a luminescing layer (a cadmium silicate) is recorded in the same way, the diagram of *fig. 10b* is obtained. The fluctuation in the light is now reduced to a ripple which is much smaller than the average constant value upon which it is superposed. As a measure of the irregularity one may choose the ratio of the difference *a* between maximum and minimum to the value *b* of the minimum. In the case of fig. 10*b* the irregularity *a*/*b* defined in this way amounts to about 0.25. It has been found that under the prevailing circumstances such a value for the irregularity may be accepted without hesitation. For the sake of comparison the variation of the light is given in fig. 10*c*, for a gas-filled electric lamp (Bi-Arlita 78 W), for which the ratio *a*/*b* is about 0.15.

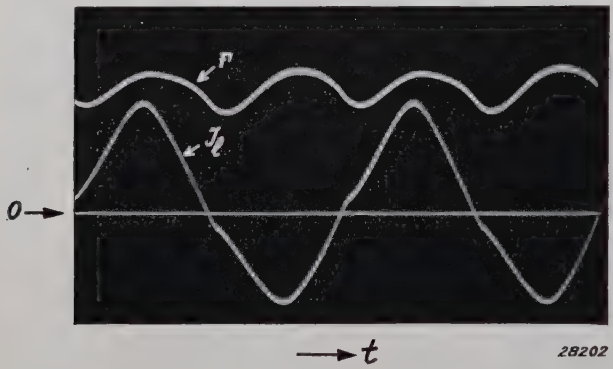

Fig. 11. Variation with time of the discharge current I_l and light flux F (sum of mercury light and luminescence light) for a low-pressure mercury discharge with phosphorescent zinc beryllium silicate (50 c/s).

In conclusion *fig. 11* gives the variation with time of the discharge current I_l, to which the intensity of the line 2537 Å is practically proportional, and of the combined light flux F of mercury and luminescence light from a tube containing zinc beryllium silicate. It may be seen clearly that there is a certain phase shift between the maxima of I_l and F, which facilitates the bridging over of the light minimum during the currentless period. The cause of the phase shift lies in what might be considered the reverse of the phosphorescence. Upon irradiation with a given, not too high, intensity of ultraviolet radiation, it takes some time before the phosphorescent substance reaches its full activity and the light emission reaches its maximum value, so that the light maximum lags somewhat behind the ultraviolet maximum.

THE TENSILE STRENGTH OF DEPOSITED WELD METAL

by J. SACK.

539.412 : 621.791.052

In this article it is shown that it is no longer correct to require in specifications an upper limit for the tensile strength of deposited weld metal. This requirement originated from an assumed relation between the variation with composition of the tensile strength and the brittleness of the material. The relation is indeed valid for ordinary carbon steels such as have long been used, but it no longer holds for modern welding materials. If this stipulation is made it leads only to the use of welding rods of poorer quality than would be used if the obsolete requirement were omitted.

Introduction

The specification accompanying an order must give the minimum conditions to be satisfied. In the case of welding rods for making joints in iron and steel the specification usually gives various requirements regarding the mechanical properties of the metal deposited and of the welded joint. For example it may be required that the tensile strength of the material deposited must be at least 42 kg/sq.mm., its elongation at least 25 per cent, and its notched bar toughness more than 8 kg/sq.cm. The elongation allows us to judge the capacity for deformation of the metal, while from its resistance to notching its toughness follows. Tensile strength and malleability are considered to be important properties of the metal and its quality increases in proportion to these characteristics properties.

It is obvious that the specifications must contain the minimum value of all these mechanical quantities. It is, however, strange that an upper limit should also be given for the tensile strength of the weld metal deposited. It would be unnecessary to concern oneself with this upper limit if only the requirement were sufficiently high ,but it often occurs that the specifications demand such a low upper limit for the strength of the weld metal that good welding rods fail to fulfil the requirement. The question therefore is why the tensile strength should not for instance exceed 47 kg/sq.mm and be 50 kg/sq.mm. The following will help to give an idea of the reason why specifications often contain such seemingly absurd requirements.

Relation between tensile strength and other mechanical properties

The tensile strength has always been the most important property for judging the quality of iron and steel. It formed the basis of the classification of steels, and on this basis the builder always made his calculations. Because tensile strength is such an important property of the metal it is understandable that attempts were made to correlate it with other properties of the material, in the first place with the hardness, *i.e.* with the resistance experienced by a ball or a diamond point upon being pressed into the material. The harder the material the greater its tensile strength. It is common knowledge that the tensile strength and the hardness of a metal vary equally with its composition.

Table I

Mechanical properties and chemical composition of several modern steels

Kind of steel	R.D.S. steel	Cor-ten steel	Cr-Va steel	Cromansil steel	Two examples of St 54	
Tensile str. (kg/sq.mm)	57.4	45-52	56-63	56-63	55.5-59.5	53.8-56.5
Yield (kg/sq.mm)	47.5	35-42	42-49	38-42	36.8-40.3	37.4-39.8
Elongation (%)	33	22-27	25-35	20-28	24.5-30.0	20.9-27.3
Decr. in cross section(%)	54	40-55	50-55	50-62	—	—
Percentage						
C	0.095	0.10	0.10-0.20	0.12-0.20	0.18	0.19-0.21
Mn	—	0.10-0.30	0.30-0.60	1.1-1.4	0.60	0.74-0.76
Si	—	0.5-1.0	0.20-0.30	0.4-0.6	0.12	0.04-0.07
Cr	—	0.5-1.5	0.80-1.10	0.7-0.8	0.62	0.23-0.28
Cu	1.44	0.3-0.5	—	—	0.60	0.42-0.43
Ni	0.75	—	—	—	—	—
Mo	0.70	—	—	—	—	—
Va	—	—	0.15-0.20	—	—	—
P	0.04	0.1-0.2	0.04	—	0.04	0.06
S	0.04	—	0.045	—	0.03	0.02

Table II

Mechanical properties and chemical composition of deposited weld steels

Material deposited		Welding rod "A"			Welding rod "B"			
		1	2	3	1	2	3	4
Tensile strength (kg/sq.mm)		46.8	47.6	52.1	48.2	48.4	51.3	52.3
Yield (kg/sq.mm)		37	37	42	38	38	40	39.5
Elongation (%)		26	27	26	22	26	29	28
Decrease in cross section (%)		42	44	42	45	51	55	52
Percentage	C	0.088	0.070	0.068	0.046	0.043	0.052	0.070
	Mn	0.44	0.47	0.48	0.40	0.41	0.48	0.44
	Si	0.14	0.13	0.21	0.08	0.09	0.13	0.15
	P	—	—	—	0.022	0.021	0.022	0.014
	S	—	—	—	0.016	0.022	0.016	0.019
	N	0.024	0.029	0.036	0.021	0.020	0.072	0.068

In the second place the tensile strength is related to the elongation at the breaking point, *i.e.* to the degree to which the metal can be deformed before it breaks. In the third place the tensile strength is related to the notched bar toughness, which quantity indicates the resistance of the metal to varying loads. With increasing tensile strength, elongation and toughness decrease. In the fourth place the tensile strength of a metal is related to its workability, which decreases with increasing tensile strength and hardness. Poorer workability is manifested for instance in the fact that the cutting speed must be reduced.

All these properties are related to each other in as far as they depend on the content of carbon which is one of the most important components added to iron to make steel. The greater the carbon content the greater the tensile strength and the smaller the elongation and toughness. This may be seen in *fig. 1* which refers to annealed carbon steel with 0.15 - 0.35 per cent of silicon and 0.50 - 0.70 per cent of manganese 1).

If steel is hardened, a hardening structure is obtained, *i.e.* a martensite, troostite or sorbite structure, depending on the rate of cooling. Martensite is very hard and brittle, while pearlite which may be obtained by annealing is less hard and tougher. In welding, the metal on both sides of the weld is heated to a rather high temperature and then cooled more or less rapidly.

If welding is done with steel having a high carbon content, hard and brittle zones must be expected. In order to avoid these undesirable structures the rate of cooling of the piece of work and the weld must be decreased. This is accomplished in practice by pre-heating. For these reasons carbon is a detrimental component in either the piece of work or the weld.

Modern steel industries pay particular attention to the development of weldable steels, and with this end in view they limit the content of carbon to, for example 1 0.20 per cent. It is now even possible to obtain steels of high strength whose

Table III

Mechanical properties and chemical composition of the material deposited from different types of welding rods

Type of welding rod		PH 38	PH 40	PH 46	PH 48	PH 50
Tensile strength (kg/sq.mm)		38-42	38-42	40-46	48-52	48-52
Elongation (%)		10-13	18-22	22-26	24-28	28-32
Notched bar toughness (kg/cm/sq.cm)		—	4-6	6-8	11-14	10-13
Bending angle (°)		—	60	90	180	180
Percentage	C	0.015	0.03	0.04	0.07	0.07
	Mn	0.07	0.02	—	0.50	0.40
	Si	—	0.01	—	0.15	0.10
	P	0.04	0.04	0.04	0.02	0.02
	S	0.04	0.04	0.04	0.02	0.02

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1) E. Houdremont, Einführung in die Sonderstahlkunde.

carbon content is low. This may be seen in the case of the steels 52 and 54 which possess tensile strengths of more than 52 and 54 kg/sq.mm respectively. In America steel 60 is being used more and more. All these types of steel have been developed on the basis of a low carbon content, so that the high tensile strength is obtained by the addition of other elements such as chromium, silicon, copper, nickel, manganese, vanadium, etc.

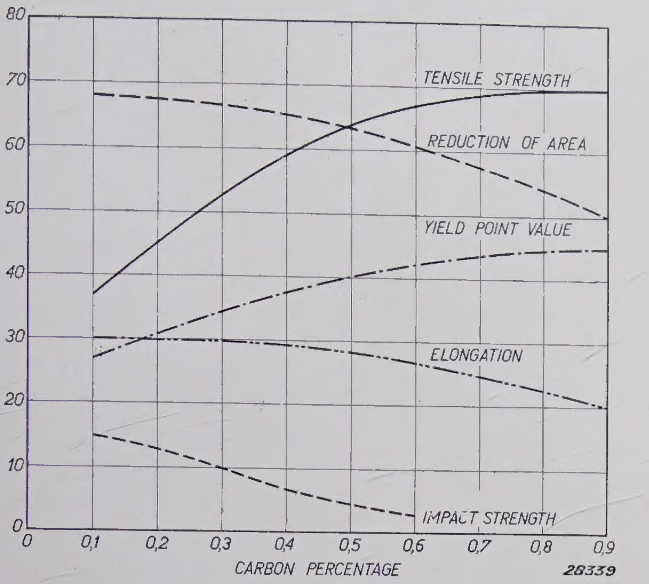

Fig. 1. The following properties are plotted as functions of the per cent of carbon: the tensile strength in kg/sq.mm, the reduction of area at the breaking point in per cent, the yield in kg/sq.mm, the elongation at the breaking point in per cent and the notched bar toughness in kg/sq.mm.

In *table I* several examples are given of modern steels which do not contain more than 0.2 per cent of carbon. Many of these steels show a remarkably high malleability and toughness.

Like the steel manufacturer, the manufacturer of welding rods must provide for a low carbon content of the fused weld metal. Usually the content is not higher than 0.1 per cent, as may be seen in *table II*. This table contains several experimental results of extensometer tests carried out in this laboratory on welding metal fused down into rods, as well as their chemical composition, including the nitrogen content. It may be seen from the table that tensile strengths of 47 to 52 kg/sq.mm. may be attained with steels containing less than 0.09 per cent of carbon. The material with the highest tensile strength contains less than 0.07 per cent of carbon. It may be seen moreover that small elongation at the breaking point need not accompany high tensile strength.

In *table III* several mechanical properties and the chemical composition of the material deposited from several types of welding rods have been collected. Welding rods with a thin coating (type PH 38 and PH 40), with thick coating (type PH 46 and PH 50) and also welding rods with organic components in the coating (type PH 48) are included. It may be seen that in general, with the welding rods in question, those with a high tensile strength also have the best mechanical properties in other respects, namely the greatest elongation and angle of bending. In any case the rule that a hard metal is also brittle is found not to be valid here. It is valid for annealed or rolled carbon steel, but not for the fused down weld metal in question.

It is true that there is a more or less close relation between the various mechanical properties of carbon steels, but it does not follow therefore that the tensile strength can be used as a measure for all the other mechanical properties, and it is certainly wrong to do so in the case of deposited weld metal in which there appears to be absolutely no relation between the different mechanical properties, so that they cannot be deduced from the value of the tensile strength.

If a high malleability or a definite toughness is desired, the desired value of that property itself must be stated in the specification.

With respect to the workability of ordinary lightly alloyed steels, it depends in the first place on the hardness and in the second place on the chemical composition and the metallographic structure. It is obvious that the workability decreases with increasing hardness, but for hardnesses with which we are concerned (about 150) the decrease in cutting speed is of no significance.

This follows from *fig. 2* [2]). The limit of the filing

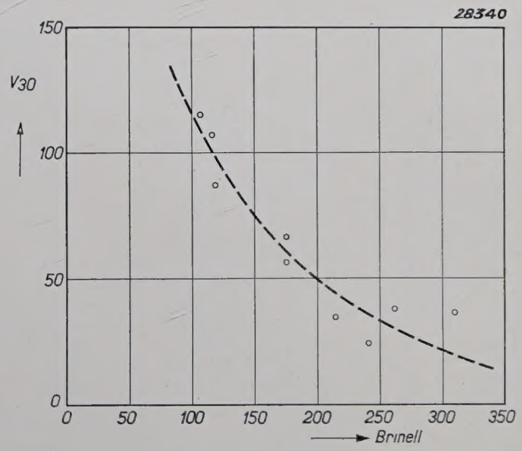

Fig. 2. The cutting speed in m/min. for a cutting edge life of 30 min (v_{30}) as a function of the hardness in Brinell units with a ball diameter of 10 mm, a load of 3000 kg and a loading time of 30 sec.

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[2]) J. R. J. van Dongen and J. G. C. Stegwee, Metaalbewerking, **3**, 49, 1936; *cf.* also P. Clausing, Philips techn. Rev. **1**, 183, 1936.

quality of the metal is so high that the differences in hardness with which we are here concerned may be neglected.

We may state in conclusion that great care must be taken in applying information obtained from experiments on rolled carbon steel to deposited weld metal. The stipulation of a low upper limit of tensile strength of the deposited weld metal can at the present time only result in the use of welding rods of poorer quality than would be used if this obsolete requirement had been omitted from the specifications.

Nature of the material deposited

We shall now study the actual differences between the metal deposited in a weld and rolled metal, and shall consider particularly the hardness. The metal under consideration consists of ferrite or α-iron and cementite or iron carbide. The hardness of the metal depends upon that of its components. Now the hardness of ferrite is very much influenced by the impurities which are dissolved in the α-iron.

Silicon and phosphorus dissolve completely in α-iron. The solubility of gases like nitrogen and oxygen is not very great but it nevertheless plays an important part. Solid solutions in general exhibit a greater hardness than pure metals, but the data on this subject are scanty. For every one-hundredth of a per cent of nitrogen the hardness increases by $2^1/_2$ to $4^1/_2$ Brinell units for example. In general the nitrogen content is lower than 0.07 per cent.

The problem in the case of oxygen is not so simple. Its solubility in α-iron is very small. The content of oxygen in the deposited metal may sometimes be very high, 0.1 per cent for instance. Oxygen combined with silicon or aluminium in the form of SiO_2 and Al_2O_3 has no influence of the mechanical properties. Oxygen dissolved in α-iron, however, increases its hardness, while the rest of the oxygen combines with the iron and manganese forming FeO and MnO whereby the hardness of the metal is decreased.

As may be seen from the following list, that deposited weld material contains more nitrogen than rolled metal:

Siemens-Martin steel: 0.001 - 0.01%,
Thomas steel : 0.01 - 0.03%,
Deposited weld metal : 0.01 - 0.07%.

This is one of the causes of its hardness.

A second cause is the fine-grained structure of the metal deposited in a weld consisting of several layers. From investigations of rolled steels it follows that a fine-grained structure produces a greater hardness: this may also be seen from the behaviour of pearlite in this respect. According to Belajev the hardness is 200 Brinell units for a mutual separation of the lamellae of 0.4 μ, while it increases to 300 at 0.26 μ.

Furthermore a slight hardening of the material deposited occurs during welding, and can be reversed by annealing the welded piece of work (*cf. table IV a* and *b*). This hardening may be caused by an incipient precipitation (so-called pre-precipitation) of compounds of carbon, nitrogen and oxygen. It is also possible that martensite is formed. There may also be other unknown causes for the hardening of the deposited metal.

Table IV

Influence of annealing and hardening on the mechanical properties of the deposited metal; a) absolute values, b) relative values

Type of welding rod	Heat treatment	Tensile strength (kg/sq.mm)		Yield (kg/sq.mm)		Elongation (%) $l = 5d$		Decrease in cross section (%)	
		a	b	a	b	a	b	a	b
PH 50	normally annealed	44.6	100	33.5	100	32.5	100	66	100
PH 50	untreated	48.7	109	39.5	118	29	89	55	83
PH 50	hardened *)	62.0	134	45.0	134	23	71	45	68
PH 48	normally annealed	47.4	100	34.8	100	32	100	68	100
PH 48	untreated	50.5	107	37.8	109	25	79	43	64
PH 48	hardened *)	63.0	133	41.4	119	19	60	36	53

*) annealed at 920 °C and quenched in water.

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS GLOEILAMPENFABRIEKEN

1300: J. D. Fast: Spanlose Formung von Zirkon und Titan (Metallwirtschaft **17**, 459 - 462, Apr. 1938).

This article discusses the working of rods of ductile zirconium and titanium to sheets and wires of only 30 μ thickness. Various properties of zirconium are determined, among others the tensile strength and stretch. The measurements were carried out on cold worked sheets and wires, as well as on material which had been annealed at various temperatures after the cold working. In connection with X-ray determinations a survey is obtained of the changes in structure which occur upon annealing.

1301: M. J. O. Strutt and K. S. Knol: On the absolute measurement of alternating currents and the calibration of thermocouples in the decimetre-wave range up to 500 megacycles per second (Physica **5**, 205 - 214, Apr. 1938).

With the help of a diode voltmeter which measures accurately to within about 1% at 60 megacycles per sec it is shown that thermocouples of different models indicate the absolute value of an alternating current with a maximum error of 2%, up to 60 megacycles/sec, when the calibration curve for direct current is used. With frequencies up to 500 megacycles/sec, for the calibration of thermocouples and the absolute measurement of alternating currents, a hot-wire air thermometer according to Scheibe is used. With these instruments and a suitable Lecher bridge circuit alternating currents of several mA may be measured accurately within 5% at 500 megacycles/sec and within 1% at 325 megacycles/sec. The errors in indication of specially constructed thermocouples also lie within these limits.

1302: F. M. Penning: The energy balance for an infinitely small electron current in a uniform electric field (Physica **5**, 286 - 297, Apr. 1938).

The portion of the energy taken up in a homogeneous field by an infinitely small electron current which is used for elastic energy losses, for excitation of higher electron and vibration states, for ionization and for the acceleration of the electrons, is calculated as a function of the quotient of field strength E and gas density for neon, argon, mixtures of neon and argon and for nitrogen and hydrogen.

1303: W. G. Burgers and J. J. A. Ploos van Amstel: Electron optical observation of metal surfaces III. Crystal growth and allotropic transition in zirconium (Physica **5**, 305 - 312, Apr. 1938).

By means of the electron microscope it was observed that upon passing the transition temperature to lower temperatures the cubic β-crystallites of zirconium pass over into a lamellar, hexagonal α-texture, whose lamellae are different for each region where a given β-crystallite was at first situated. This α-texture recalls that of martensite steels. Upon increasing the temperature the original β-crystallites are recovered, and they may again be transformed into practically the same α-lamellae and so on. From this behaviour it follows that we are concerned with a homogeneous change in form of coherent lattice regions, which by slip and stretch in definite crystallographic directions pass from the one state to the other and the reverse, so that the whole process resembles the manner in which martensite needles occur in steel. At temperatures above 1150° C the β-crystallites exhibit a crystal growth in which the velocity of growth of the individual β-crystallites may be influenced by causing a temporary transition into the α-modification.

1304: W. G. Burgers and J. J. A. Ploos van Amstel: Electron optical observation of metal surfaces IV. Appearance of "lines" of high emissivity on nickel-iron crystals (Physica **5**, 313 - 319, Apr. 1938).

A crystal of nickel-iron activated by strontium and barium exhibits under the electron microscope a "normal" emission pattern according to its crystal structure. If an additional amount of strontium and strontium oxide is now applied to the cathode while it is kept at about 900° C, the emission increases in intensity not only over the whole surface of the cathode, but in addition it becomes unusually intense at individual points which are arranged along parallel lines. The direction of these lines is connected with the orientation of the crystal lattice, because the lines usually run from one crystal boundary to the other. Furthermore when the excess activating substance is removed by heating for a short time at a higher temperature, and when activating atoms are then deposited again on the surface under the same conditions, the lines reappear with practically the same direction.

1305: J. H. de Boer and J. D. Fast: The diffusion of hydrogen through regenerated cellulose and some cellulose derivatives (Rec. Trav. chim. Pays Bas **57,** 317 - 332, April 1938).

In the diffusion of hydrogen through metals the molecules are dissociated into atoms. In other media, such as acetylcellulose for example, hydrogen dissolves in the form of molecules, so that a diffusion of molecules may be expected, *i.e.* a diffusion proportional to the gas pressure. On the basis of the structure of cellulose and cellulose derivatives it may be expected that diffusion will occur more easily through the cellulose derivatives than through cellulose itself. Nitro and acetylcellulose are practically impermeable to air although not to hydrogen. Regenerated cellulose is practically impermeable to either gas.

The dependence of the rate of diffusion of hydrogen on temperature was investigated. For the case of nitrocellulose the dependence on pressure was studied and a proportionality was found. The diffusion was found to be practically the same for nitrocellulose and technical celluloid. The increased permeability of acetylcellulose for hydrogen compared with regenerated cellulose is found not to be due to a smaller activation energy, but to a greater number of paths per sq.cm suitable for diffusion, which in turn is perhaps due to a smaller size of micelles. In the case of nitrocellulose a smaller activating energy plays a part.

1306: E. J. W. Verwey and J. H. de Boer: Dilatancy (Rec. trav. chim. Pays Bas **57,** 383 - 398, April 1938).

A plastic mass for instance of iron filings with a non-polar liquid can be made fluid with a trace of oleic acid. The liquid so obtained can then still be considerably thickened, *i.e.* the particles of iron may be packed much closer together. Certain other substances exhibit the same behaviour. The liquids thickened to the correct concentration exhibit remarkably well the phenomenon described by Osborne Reynolds of becoming solid under the influence of rapid and acute deformations, it is called "dilatancy".

From the investigations there seems to be a simple explanation of this strange phenomenon. The solidifying under the influence of rapid and energetic deformations takes place because of the fact that the repulsive forces between the particles, due for instance to the polar film of oleic acid, are overcome locally.

1307: J. F. Schouten: Properties of variable width sound film as an optical diffraction grating (Nature, London **141,** 914 - 915, May 1938).

The employment of sound film as an optical diffraction grating suggests the investigation of the diffraction patterns which are produced by sound film with a variable width of the sound track. These diffraction spectra are much more complicated than those produced by sound film with variable transmissibility of the track. At the same time, however, they make possible an immediate analysis of the sound into its different components. The action of ordinary diffraction gratings is based on change either of the amplitude or of the phase of the incident light. Sound film with variable transmissibility of the sound track belongs to the first type. Sound film with variable width of the sound track, however, is a third, new type of optical diffraction grating.

1308*: F. A. Heyn: Radio-activity induced by neutrons (Diss. Delft 1938; 96 p.).

Two types of apparatus are described for the production of neutrons by means of high voltages (up to 600 kilovolts). Many substances were bombarded with neutrons produced by these apparatus, and new radio-active nuclei were found as well as a new type of reaction. A survey is given of the nucleus reactions which may be obtained by bombarding different substances with neutrons.

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*) An adequate number of reprints for the purpose of distribution is not available of those publications marked with an asterisk. Reprints of other publications may be obtained on application to the Natuurkundig Laboratorium, N.V. Philips' Gloeilampenfabrieken, Eindhoven (Holland), Kastanjelaan.